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Walther Brand

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PROBLEME DER KOSMISCHEN PHYSIK

Problems of Cosmic Physics

DR. WALTHER BRAND

BALL LIGHTNING

(Der Kugelblitz)

II./III.

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PREFACE

The inflation of our currency which has reached proportions beyond all comprehension and the resulting price increases, especially in the paper and book-printing idustries, have dealt a heavy blow to our young enterprise. Even a relatively small edition involves such high production and miscellaneous costs that in most cases the publication of a book becomes economically unfeasible. Under the prevailing conditions a market wide enough to cover the publication costs is unthinkable.

Thus, the Editors and the Publisher see themselves forced to temporarily delay the publication of the work, which was begun with such fervor and high hopes, and was enthusiastically hailed in wide circles, until times arrive in which intellectual activity can once again flourish.

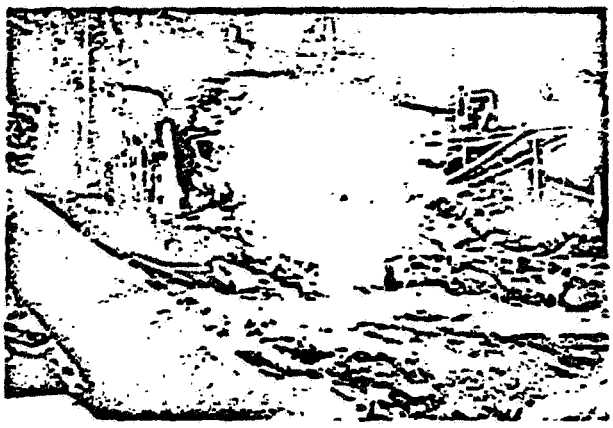
In the meantime, it is the task of the Editors and the Publisher to search for means whereby the publication of at least those works for which manuscripts already exist can be implemented.

In bidding our friends farewell, we hope that we will meet again in the near future.

"Per aspera ad astra" is hereto our slogan.

Hamburg, Autumn 1923

Chr. Jensen



Fire, Ball lightning

Luminous phenomena occurring during the shorting of a generator.
Point of short-circuiting

INTRODUCTION

The problem of ball lightning. "There is only one instance," writes F. Arago in his classical treatise — "Sur le tonnerre"[1]) — in which the physicist cannot accomplish what nature can effect with so much ease: he cannot produce lightning in the form of a ball; in fact, he cannot produce ball-shaped accumulations of matter which move slowly yet strike like lightning." These lines, written in 1838, which also indicate the behavior of ball lightning in contrast to ordinary lightning, are still valid up to this day, despite all the studies since made in this direction.

Since ball lightning was regarded as a "stranger" among atmospheric phenomena, man went even so far (as in the case of meteorites) as to deny its existence and to consider it as belonging to the realm of fables. It was asserted that ball lightning was a manifestation of optical illusions, after-images on the retina, or that the observers were victims of their imagination, etc. Thus, the publisher of Arago's works, Hankel[2]), writes: "Without going into a long-winded discussion on this subject, I would merely like to remark that in my opinion the slowly moving fiery balls, such as were mentioned, for example, by Babinet[3]), and such as Hapouèle[4]) witnessed from a dung pit as they first moved horizontally and then obliquely upwards, etc., do not exist in reality, and are nothing else but subjective optical phenomena, such as after-images left on the retina of the eye owing to the "blinding" effect of the preceding lightning." Verdet[5]) gives the following explanation: the blinding, which is caused by a lightning flash directed straight toward the observer, produces a persisting circular image on his retina which then seems to follow some trajectory, whereas in effect he is unconsciously moving this image each time he changes his direction of view. F. v. Schiödt[6]) claimed to have found in a number of cases of ball lightning investigated by him that the assertions of the observers with regard to the size and distance of the ball always led to the same angular size, and in fact corresponded to the size of the blind spot in the eye. In doing so, he saw fit to conclude that ball lightning was merely a subjective phenomenon. However, since the angular dimensions of the blind spot fluctuated between 3°39' and 9°47', the total size of the invisible area corresponded on the average to about eleven times the apparent size of the moon; thus, ball lightnings must also be of this order of magnitude, which, however, by no

[1]) Arago, F. Collected Works. — German edition by W.G. Hankel. Vol. 4, p. 325.
[2]) op. cit. Vol. 4, p. 45, annotation.
[3]) See Report No. 210 in the present collection.
[4]) Idem, No. 8.
[5]) La Nature 18, 203, 1890, 2nd half-year.
[6]) Tidskr. f. Physik og Chemi, 2. 242—245. 1893.

means is the case. Also Grimsehl[1]) expressed himself with extreme caution, when he stated: "Ball lightning, if it really exists and is not merely a figment of the imagination, represents without doubt the most mysterious form of lightning."

The descriptions of many ball lightnings, however, in no way concur with the assumption of subjective illusions. Of course, many accounts, namely those dealing with "fireballs," a designation frequently used by the observers, must be subjected to careful scrutiny. Below, we shall show how in many cases, which incidentally have also been cited in the literature under the designation ball lightning, it can be said with certainty after closer examination that there is no question of ball lightning. Moreover, it should be pointed out that many reports ofiginate from people, who probably lacked the ability to make rapid and reliable observations, and that the observers must have frequently lost control of their emotions, so that a critical evaluation of their reports is certainly called for.

On the other hand, however, there have been numerous and well-documented reports of ball lightnings which give the impression of absolute objectivity. Many ball lightnings were simultaneously observed by several people and similarly described; occasionally, certain people observed the phenomenon only after their attention was drawn to it by others. The objective existence of ball lightning must therefore be regarded as established.

Unfortunately, there exists, insofar as the author knows, no photographic evidence of a ball lightning. In 1902 the reproduction of an alleged photograph of a ball lightning, taken by an amateur photographer on 4 September 1902 in Berlin, was circulated in several journals. However, the circumstances under which the photograph was taken were checked and the same camera was used to photograph the surroundings of the observation site with the remarkable result that the peculiar lines of the photographic plate were due to the presence of a street lantern, whose images on the photographic plate traced out the strange pattern when the camera was moved while the objective was open.[2]) There only remains the color handdrawing of a ball lightning made by v. Haidinger (see Report No. 31).

Aim of the present work. Any experimental study of the nature of ball lightning as well as any theoretical deliberation must, in the author's view, be first preceded by a comprehensive compilation of the observational data on the ball lightning phenomenon, its appearance, its formation and extinction, which is only possible on the basis of original accounts.

The first task of the present work must therefore consist in accumulating and critically selecting the various reports and accounts which have appeared in numerous journals in order to obtain suitable material. If course, not all the recorded accounts of "ball lightnings" or "fireballs" were used. As mentioned before, many alleged ball lightnings proved after closer examination to be merely cases of ordinary lightning and were consequently not classified. In other cases, namely those dating from the eighteenth century, the mere nature of the description already indicated that these were not original accounts; however, it was impossible to establish the sources. These reports, as a rule, were likewise not used. In all cases the accounts were subjected to the strictest possible criticism. On the other hand, the

[1]) Grimsehl, E. Lehrbuch der Physik (Textbook of Physics), Vol. II, p. 428. 1916.
[2]) Prometheus 14, p. 234. 1903.

present collection is by no means conclusive; the effort and time required to accomplish this (without considering the difficulty involved in incorporating information dating from the period of World War I and the years of the Revolution) would in the author's view not have yielded invaluable results; on the contrary, since the present work involved the assessment of several hundreds of reports, it seemed much more expedient to impose a limitation on the period to be covered. Consequently, with the exception of isolated instances, it was decided to disregard older reports and to reproduce only those accounts dating from the last hundred years.

Similar attempts have already been made to clarify the phenomenon in question by compiling accounts from original sources. Mussenbroek[1]) was the first to compile a small survey comprising ten reports dating from the first half of the eighteenth century. A similar collection was compiled by Arago[2]); this survey contains 30 accounts mostly dating from the eighteenth century. Later, in a study performed over several years Sestier[3]) produced a comprehensive survey of lightning strokes of all types, including a series of events associated with ball lightning. Further reports were compiled by Planté.[4]) Subsequently, Sauter[5]), who based his study largely on the last-named sources, produced a survey totalling 179 reports. Moreover, in his collection several lightning events have been listed twice; this was a result of the fact that many of the events recorded in his survey were taken from the compilations of his predecessors and were erroneously considered as isolated events owing to a superficial assessment (e.g., 139 and 144, 78 and 146). A small survey was also made by Flammarion[6]) and Gockel[7]). However, a large number of the reports appearing in these collections give the impression that the alleged ball lightning event was in fact ordinary lightning or perhaps a meteor. This especially applies to many events mentioned in the articles of Galli[8]). Moreover, he made no reference to original sources, but complied with extracts or merely with citing isolated phrases.

In the present work reference it always made, insofar as possible, to the original sources; in certain cases this resulted in departures from the above-mentioned surveys, since these in turn partly originate from second-hand information. The present author based his study primarily on the scientific periodicals, reports of scientific associations, etc., present in the library of the University of Marburg and which were systematically scanned for articles on ball lightnings. Further periodicals, especially those from foreign countries, were acquired on loan from the libraries of the University of Berlin and of Göttingen as well as from the German Marine Observatory at Hamburg; however, the turmoil of the Revolution unfortunately slowed down the postal service and at times even brought

[1]) Van Mussenbroek, P. Cours the Phys. exp. et math. 3, pp. 405—406. 1769.
[2]) Arago, F. op. cit.
[3]) Sestier, F. De la foudre, de ses formes et de ses effets. — Paris, 1866, 2 Volumes, published by Méhu.
[4]) Planté, G. Les phénomènes de l'atmosphère. — German edition published by G. Wallentin, Halle. 1889.
[5]) Sauter. Über Kugelblitze (On Ball Lightnings), Supplement to the curriculum of the Royal Realgymnasium at Ulm. 1890 and 1892.
[6]) Flammarion, C. Les caprices de la foudre, Chapter IV. Paris.
[7]) Gockel, A. Das Gewitter (The Thunderstorm), Cologne. 1905.
[8]) Mem. della Pontif. Accad. Rom. dei Nuovi Lincei, 28, 217—278. 1909; 29, 251—318. 1910; 30, 257—315. 1911; 31. 225—295. 1912.

it to a complete standstill. Among the approximately 600 reports accumulated in this manner 215 of the most carefully written and best documented accounts (several of which comprise several ball lightnings) dating from the last hundred years were selected as a basis for the present treatise. Below, 108 of these have been reproduced verbatim. Only a few comprehensive accounts dating from earlier periods have been included.

11 Selection of the reports

a) Confusion between ball lightning and streak lightning. It was often difficult to establish with certainty whether the event in question was in fact a manifestation of ball lightning. Ordinary lightnings and meteors are too frequently mistaken for this form of lightning. The care which must be taken in assessing whether a fireball was actually observed is illustrated by the following example: on Monday July 10, 1843, at 1.30 p. m. a heavy thunderstorm broke loose over Strassburg. The lightning struck the cathedral, i.e., its lightning rod, twice. Several people claimed to have seen a fireball, which enveloped the upper portion of the lightning rod and slid downward along its surface. Only the telegraphist, who observed the event from a vantage point better than that of any of the other observers, assured us that he could only distinguish a luminescent streak which extended from the point of the tower to the platform of the lightning rod, whereby the latter became invisible to him.

Several other typical cases, which probably involve streak lightning, can be mentioned here. In reports on remarkable lightning strokes, which at the time or later were described as ball lightnings, we repeatedly encounter the phrase: "The lightning struck in the form of a ball" (see Sestier 1, 135, 146, 147 ..., and Sauter No. 9, 10, 20, ...). Another expression: "The lightning appeared as a ball" appears very frequently in the reports on lightning strokes of Weber and Brodersen[1]) (see the reports of 13 June 1880, 23 June 1880, 2 July 1880 ... or Nos. 1766, 1741, 1957 and others, as well as Sauter Nos. 47, 48, 49, 50, 51, 56, etc.). In other reports we read "It seemed as if a ball of fire burst into pieces on the roof" (Sauter 52), "Fireballs fell from heaven" (Sauter 1), "The street seemed to be engulfed in a convulsive flame, which appeared to others as a large, brilliant white ball; at a larger distance some observers claimed to have seen a wide zigzag streak, which seemed to have struck an adjacent building" (Sauter 60 after Neesen, "Die Blitzgefahr" (The Lightning Hazard, No. 2, p. 29). "After the lightning penetrated a blue sparking flame having the character of a brush discharge shot out of the valve head" (Sauter 126). In all these cases it is very doubtful whether ball lightning actually occurred. Even if these accounts were associated with this phenomenon, such accounts are of no value for the investigation of the properties of ball lightning and thus were not included in our collection. Also in other cases, such as illustrated by the following example, it is difficult to arrive at a decision: "With a blinding flame, which seemed to rise from the ground, and with a frightning detonation a ball approximately 40 cm in diameter which was vividly colored

[1]) Weber, L.; Brodersen, H., respectively. Berichte über Blitzschläge in der Provinz Schleswig-Holstein (Reports on Lightning Flashes in the Province of Schleswig-Holstein). — Publications of the Natur-Verein f. Schleswig-Holstein. Series 1—4. Kiel.. 1885 and 1909, respectively.

and enveloped in flames smashed into the tower of the castle and left a vertical hole of almost 10 m."[1]) It may very well have been that in this case it actually was ball lightning, if the event was correctly observed despite its rapidity and brightness. However, even in such cases illusions are still quite probable as in the cases of more persistent ball lightnings. On the other hand, if the accounts can be considered as irreproachable, then on the basis of such examples it would follow that the phenomenon involves transitional forms from streak lightning to ball lightning. These transitions are also of importance for the explanation of the phenomenon even if not to the same extent as the typical forms. Consequently, only a few very clear examples of this kind have been recorded.

In the following examples, however, we may very well be dealing with streak lightning: a "beam of fire" was seen coming from the direction of the thunderstorm; this was considered by Galli as a clear example of a ball lightning under clear-sky conditions: "It could not have been a streak lightning, because the mass had dimensions corresponding to those of a beam."[2]) In another case[3]) a "fire mass" is mentioned. Here, a poplar was struck by the lightning in the usual manner, an electrical return stroke occurred, etc.; nevertheless, Galli was of the opinion that this could only have been a manifestation of ball lightning, since the clouds of the thunderstorm were only at a distance of 3 km.

Galli in general bases his assessments on the premises that each peculiar form of lightning is to be designated as ball lightning. More than once we encounter the reasoning that the effects of the lightning flashes are of such a type that there is no question of streak lightning[4]), or he states: Although the type of lightning is not given in the reports, it can nearly always be concluded from its course and effects that ball lightning is involved[5]). Or: The spherical form was not specified, but we must assume this as the true form, since it is impossible that gunpowder can withstand the heat generated by an ordinary lightning[6]).

It further seems very peculiar, when Galli cites the following example as a manifestation of a "black" ball lightning[7]): In the afternoon of April 13, 1832, a married couple observed in a completely clear sky the approach of a very ominous small black cloud which emitted flashes and caused serious damage. Likewise fantastic, if not mystifying, is a description in Latin dating from the first half of the seventeenth century which Galli[8]) likewise considers as a manifestation of ball lightning. The translation reads as follows: I twice saw a type of black canister as long as a horseman's greaves flying noisily around in an oak forest; at the rear there was a flame such as that from burning straw. Thereupon, a heavy downpour followed.

Ignoring fantastic descriptions of this type, then in most of the above-cited cases, whose number could be increased at will, we are not dealing with ball lightnings but rather with the phenomena and effects of ordinary

[1]) Galli. Mem. Pontif. Accad. Rom. dei Nuovi Lincei, 28, Chapt. 27. 1909.
[2]) Idem, 30, p. 263. 1911.
[3]) Ibid., 30, p. 264. 1911.
[4]) Ibid., 30, p. 302. 1911.
[5]) Ibid., 30, p. 294. 1911.
[6]) Ibid., 30, p. 282. 1911.
[7]) Ibid., 28, Ch. 29. 1909.
[8]) Mem. della Pontif. Accad. Rom. dei Nuovi Lincei 28, Ch. 29.

lightning flashes. The blinded observer usually has the impression of a "fireball" or "firemass" when a lightning discharge strikes in his vicinity. However, we must bear in mind that the point at which the lightning strikes is always brighter than the remaining part of the lightning flash. Consequently, the event would arouse the notion of a luminescent ball, whereas more remote observers perceive the phenomenon in a completely different form.

In other cases we cannot exclude the possibility that the event involves only the bottom part of the lightning, i.e., the fork, or perspective nodal points along the lightning network. As an example we cite Arago 4, 33 of 16 July 1750 (Sauter No. 8): Large fiery balls were observed in the air around the house where the lightning struck; upon arrival on the ground or on the roofs of the houses they exploded into a large number of pieces which were strewn in all directions. The intensely luminous end of a lightning stroke was also described in Weber's survey[1]), "Blitzschläge" (Lightning discharges), page 14, of 12 June 1880 (Sauter No. 46): The lightning took on the form of a bright ray of light; upon hitting the top of the roof a fiery ball was allegedly observed.

When taking all these possibilities into consideration, we are already compelled to exclude a whole series of reports of alleged ball lightnings. In addition, allowance must be made for the fact that many accounts of lightnings in the earlier collections were cited which in the original reports were never designated as ball lightnings, and at times are explicitly cited as streak lightnings. Thus, in Sauter Nos. 42, 48, 49, which were originally taken from Weber, the words "The lightning appeared as a fiery ball" are followed by a question mark, which was left out by Sauter. Further, the lightning event described in No. 50 of the Sauter collection: "It appeared as a fiery ball" was explicitly designated as farfetched in the original. The explanation for this is probably due to the fact that Weber changed his view concerning the nature of many of the lightning events compiled in his collection and subsequently expressed this in a later edition. However, he even cited two cases of alleged ball lightning, while after closer examination it was found that the observer was by no means certain about the course of the phenomenon. Thus, on the basis of the above-cited examples it can be seen how difficult it is to determine whether the observed event is truly associated with ball lightning.

Also the criterion that a certain time interval elapsed for the lightning to cover a measurable or assessable distance is not always adequate. Such statements should often be treated with some reservation. It is known, for example, that while a lightning stroke is simultaneously visible over its entire extent, observers describe the event as a succession of effects. Thus, on the basis of such data the rapidity of the process is often estimated as low and the conclusion is drawn that the phenomenon must have involved a ball lightning. The undertainty in the time is especially apparent in accounts given by women (Sauter 45, 90). Further, errors in translation occur, such as, for example, in Sauter No. 89 after Arago page 43: several minutes, whereas the original[2]) says several seconds.

There are further factors that should be mentioned which lead to misunderstandings. Thus, information concerning the distances and locations

[1]) Weber, op. cit.
[2]) Comptes Rendus, 35, 2.

at which the ball lightning appeared and disappeared are often subject to doubt; very frequently the distances are underestimated. One observer (see present collection No. 8) claimed that the electric ball described a slanted trajectory toward the clouds after having passed the cornice of the house at a distance of $1^1/_2$ feet. In all probability the observer had no possibility to estimate the distance; the same applies to No. 5 of the present collection: the fireball flew at great speed past the window at a distance of about 15—20 m and disappeared without leaving a trace on (in reality probably behind) a steep tile roof.

Also in accounts of ball lightnings observed under clear-sky conditions it is probable that in most cases the alleged absence of clouds is merely associated with inaccuracies in the description or lapses of memory, since it is quite possible that fair weather and perhaps even sunshine prevailed before the phenomenon was observed. Galli dedicated an entire chapter to ball lightnings observed during fair weather. Despite the fact that he admits to the possibility of illusions, he still believes in a case in which a lightning in the form of a red tongue whizzed past the ear of a woman[1]), whereby he guarantees complete independence of any thunderstorm, since he was convinced that on the day in question and even on the days preceding and following (!) the event not a single thundercloud was visible over Latium and its surroundings. If the above description seems unconvincing, then this is even more evident in Galli's generalization that lightnings observed during fair weather "cannot be actual sparks of fire" but only ball lightnings or at least lightnings of some definite shape[2]).

Galli also studied the alleged ability of ball lightning to form images which took on some definite shape. Besides several examples, which did not seem to him as absolutely certain manifestations of ball lightnings, he cites two cases in which ball lightnings doubtlessly produced such impressions. Let us mention one of these here[3]): In Troyes on the evening of July 26, 1873, during a violent thunderstorm a ball shot out of the hearth, passed the shopkeepers at very close range, but then turned around and disappeared. On the premises definite marks of a decorative nature were later found on the furnace door and in fact with distinctness of detail only comparable to that obtained with photographic devices of the highest quality. "In this case," Galli claims, "the decorative marks extended from the bottom up to a height of several meters," and adds: "if the observer of the event had reported the furnace material, height of the door, size, color and position of the impressions, the observation would have been of far greater significance." Here we are probably dealing, as in most cases of this sort, with the usual signs of a lightning stroke to which the fantasy attributed definite impressions. However, sometimes such impressions actually occur, but only in cases where objects are in contact with one another, such as, for example, a coin which leaves an impression on a hand. These impressions can be verified in a laboratory.

In a later chapter Galli also treats lightnings which melt and vaporize metals[4]). It is much more probable that in connection with the latter

[1]) Met. Zs. 20. 188; Report No. 152 of this collection.
[2]) Op. cit. 30. 264. 1911.
[3]) Op. cit. 30. 304. 1911.
[4]) Op. cit. 30, Ch. 12.

process robbery is involved, since repeated mention is made of the disappearance ("vaporization," according to Galli) of gold necklaces, rings and the like, without leaving a trace. Thus, on September 21, 1901, the necklace of a woman fatally struck by lightning in the district of Narbonne was "vaporized" to such an extent that no trace was left. — On January 17, 1914, a ball lightning tore away an earring of the Madonna which was never again found[1]). It is quite strange that Galli never considered the feasibility of explaining these events as simply due to theft.

b) Confusion between ball lightning and meteors. This occurs quite frequently, which is not so surprising at a time when no specific designation existed for ball lightnings and these were partly classified as fireballs, whose nature was likewise unknown up until a century ago, when Chladni[2]) published his treatise. This confusion is also connected with the fact that meteorite fragments were designated as lightning stones, a conception which was upheld well into the Middle Ages and which is also associated with the currently still commonly used designation of certain fossils — the belemnites — as thunderstones. However, also in more recent times there are still numerous cases in which meteorites are mistakenly interpreted as ball lightning; doubtful in this respect are cases in which it is claimed that the lightning occurred under conditions of a completely clear sky. As an example we cite Sestier 27 (Sauter No. 140): At Lyon on a very cold windstill day with clear sky (November 29, 1849, 9.30 p.m.) a large fiery mass of solar brightness was seen passing in a straight line from west to east over Perache peninsula and then crashed into an entrenchment of the fort. The ball faded and then performed several revolutions without causing the least noise or striking any person in the vicinity (during this process an odor like that produced by the burning of sulfur was perceived. The meteor left a smoke trail along its trajectory through the atmosphere)[3]). No signs indicating the presence of a solid body were left behind. Further examples can be found in Sauter No. 92 after Klein: "The Thunderstorm,"
17 34: From the center of a dark cloud emitting lightning flashes appeared a curved red fireball which approached the ground with a thundering report and emitted a very bright light; the remaining parts of the ball fell into the sea causing a violent spray; further examples are cited in Sauter 27 after Met. Zeitschift 1889, 400 and Sauter 21 after Arago 35 as well as in Sauter 1, 141. Similar misinterpretations are found in Galli's collection[4]). On April 3, 1876, in Avignon a fireball the size of a full moon was observed which transformed itself into a flying rocket comprising all the colors of the rainbow and then separated into three points, each of which exploded into a star similar to that observed during a fireworks display. Two loud thunderclaps then followed. Here, we are informed about an event involving a detonating meteor. A color transformation was displayed by the following meteor, which Galli likewise erroneously interprets as ball lightning (ibid.): On the evening of July 24, 1790, a type of rocket was seen rising above several clouds which became thicker, changed color twice, started to flash and then ejected, without producing the slightest

[1]) Atti della Pontif. Accad. Rom. dei Nuovi Lincei p. 290. 1914.
[2]) Chladni. Über Feuermeteore und die mit denselben herabgefallenen Massen (On Fire Meteors and Masses that Have Fallen Down with Them). — Vienna. 1819.
[3]) The parenthetical phrases are not included in Sauter's version.
[4]) Op. cit. 28. Ch. 25.

explosion, a bright, vivid silver ball, which dropped back into the clouds and disappeared. A clear manifestation of a meteor with change of color is also the fireball of 7 June 1879 at Geneva[1]) which was designated by the reporter as a ball lightning: From the clouds plunged, before any kind of thunderclap was heard, a completely round, yellowish white ball, which moved away from clouds in the direction from SSE to NNW. According to some observers it emitted a whitish red light, according to others a green-fringed red light; the speed of flight of this gigantic meteor was extraordinarily high; it disappeared after 3—4 seconds behind the mountains, so that nobody could have seen the final phase of the event. The meteor surprisingly displayed a vivid oscillating movement along its entire path and left behind a luminous trail like that of a large rocket. "In short, it was a ball lightning," states the reporter. We would say: "In short, it was a meteor."

Several cases in which meteors are confused with electrical phenomena recorded by the "Gewitterbeobachtungsdienst" (Thunderstorm Observation Bureau) are reported by Hennig[2]). One example will suffice: in forecasts of January 6, 1914, from Gershausen a distant thunderstorm was reported at 7.45 to 8.00 p.m. at $-8°$ C; during a partly overcast sky several steeply rising, crimson-colored ball lightnings were allegedly seen which were subsequently followed by moderate thunder. Also a meteor consisting of a ball and a tail had allegedly smashed into the ground. The assumption of a thunderstorm was excluded because of the definite anticyclonic weather conditions. Thus, the report could only have been motivated by the downfall of two meteors, which is further borne out by the fact that according to other reports made at the same time various meteors had been seen. Consequently (states Hennig after citing further examples), in winter during calm, frosty weather we can always safely attribute isolated flashes to meteors.

On the other hand, electrical phenomena have also been misinterpreted as meteors. Thus, in Kämtz's fireball catalogue[3]) the events observed on December 17, 1824, and November 12, 1820, were probably ball lightnings.

Even tornadoes have, surprisingly enough, been mistaken for ball lightnings; for example, by Galli[4]): On July 29, 1686, after 5.00 p.m. an ominous dark thunderstorm appeared in the district of Libecchio, covering, as it were, the entire horizon between east and west of Libecchio. From time to time the thunderstorm seemed to split up into sudden, but faint lightning flashes, which were accompanied by fearful and persistent thunder. Those, who saw the storm and despite its fury were undaunted in observing its peculiarities, reported in conformity that the thunderstorm passed over in less than seven minutes, that the air was heavy, had a sulfurlike odor, and that it consisted of clouds of such density and blackness that it rendered near objects in the field of view invisible, that in the heart of this darkness small, white, continuously roaring clouds with broad fire-streaks were seen whirling about in a circle. From three cliffs these vapors seemed to be less dense and furrowed by white flashes, but nevertheless the air seemed to be, as it were, of a fiery color.

[1]) Comptes Rendus, 88, 1319, 1879.
[2]) Das Wetter, 14, 252.
[3]) Kämtz, L.F. Lehrbuch der Meteorologie (Textbook of Meteorology), Vol. III, p. 264 ff. — Halle, 1836.
[4]) Op. cit. 30, 275.

The above-said should suffice to illustrate how many of the phenomena designated as ball lightnings in the various compilations and journals should be a priori excluded. The collection of Sauter seems for this reason not sufficiently critical, while the completely uncritical statements of Galli merely cause confusion instead of establishing facts.

SELECTED REPORTS

1. 29 June 1965. 5 p.m. Bremen. Abhdlg. Naturw. Ver. Bremen 13, 312, 1896.

On page 307 of his diary (Archives P. l. h. 6. a) Mayor Henricus Meyer writes the follcwing about a ball lightning observed here in June 1665:

At 5 o'clock in the afernoon of June 29 an unexpected thunderstorm with lightning, heavy rain and hail broke loose. An explosive thunderbolt was heard which everyone thought had struck his own house, but the entire event took place without causing any damage in or outside the city. However, immediately after the above-mentioned thunderclap a most remarkable thing happened. A fireball entered the front door (while several women were present in the house) of the former residence (now inhabited by Dr. Med. Paulus Glaudorff) of my sister (widow of the late Mayor of Line) near the weighbridge on the Langestrasse. The fireball rolled into the house, burst into flaming pieces and then once again formed a ball or sphere of fire; it thereupon rolled via the front door out into the Langestrasse, down a sidestreet — the Wilckensstrasse — and once again burst, whereupon it finally flew up into the air without causing any damage.

2. July 1744. Knifvings Gut. Sestier. De la foudre, de ses formes et de ses effets. 1, 119. Paris 1866.

On a day of the month of July 1744 a menacing cloud appeared over Knifvings Farm; the thunder came nearer and nearer. A farmer's wife was busy cooking at the kitchen fireplace, when suddenly a lightning bolt struck and she witnessed a fireball about the size of a fist coming out of the chimney. The fireball passed between her feet without causing her any bodily harm and continued along its path without igniting or knocking over the spinning wheel and several other objects standing on the kitchen floor. Terrified, the farmer's wife dashed to the door; just as she was about to open the door the fireball came leaping towards her, passed right by her feet, then entered a room, which had an exit to the outside, traversed it, crossed the threshold and then entered the farmyard. After crossing the yard, it passed through the door of a shed, ascended toward the adjacent wall and then climbed up its outer side. Upon arriving at the edge of the straw roof it exploded and disappeared with such a dreadful bang that the farmer's wife fainted. The shed caught fire and burned down completely. The clergyman Tiburtius documented this report in the presence of the farmer's wife, her husband and the maid.

3. 29 August 1791. 2 p.m. Ginepreto. Sestier. De la foudre, de ses formes et de ses effets. 1, 119.

In a letter of the Abbé Spallanzani to the clergyman Barletti mention is made of an event, which took place in the vicinity of Ginepreto, not far from Pavia, during a violent thunderstorm accompanied by lightning and thunder: a flock of geese were feeding on a meadow at a distance of about 150 paces from a farmyard. A young girl about 12 years old and another, still younger girl ran out into the meadow to drive the geese back to the farmyard. A 9 or 10-year-old boy and a man of about 50 were also present. Suddenly, a fireball about the size of two fists appeared at approximately 3—4 feet from the young girl and crept over the gound; it moved rapidly toward the bare feet of the girl and disappeared underneath her skirts, then appeared again in the form of a ball at about the middle of her bodice and then ascended into the air with a loud noise. The instant the fireball disappeared under the girl's skirts, the latter widened like an umbrella when opened. The details of the event were not reported by the stricken girl, who collapsed immediately, but by the young boy and the man, who, when separately questioned, gave the same description of the event. "No matter how often I asked them," writes Spallanzani, "whether at the moment in question they had seen a flame shoot out of the clouds and strike the girl, they persistently asserted that this was not the case, and maintained that they had seen the ball move from the ground upwards and not from the cloud toward the ground." On the body of the girl, who soon regained consciousness, a superficial indentation, extending from the right knee to the middle of the chest, was found. Her blouse was torn to shreds at the corresponding places and the traces of burning disappeared after washing. The country physician Dr. Dagna, who examined the wounded girl a few hours after the accident, found in addition to the above-described indentation several superficial, curved, blackish streaks, which represented the side traces of the main portion of the lightning. No signs of the presence of a fireball were found on the meadow in the vicinity of the site.

4. 3 August 1809. Afternoon. Newcastle. Arago 4, 38.

On 3 August 1809 lightning struck the house of Mr. David Sutton not far from Newcastle-upon-Tyne. Eight persons were having tea in the living room, whose fireplace was struck by lightning, when suddenly a fireball appeared on the floor next to the door opposite the fireplace; the fireball remained motionless for some time, so that it could be clearly seen by all those present. Thereupon the fireball moved to the middle of the room and burst into several pieces, which in turn exploded like rockets.

5. 26 August 1821. Épinal. Ann. de Chemie et de Physique 19, 86, 1821.

6. 1826. Altona. Comptes Rendus 36, 745, 1853.

From a letter of the physician Steinmann, Altona, to Arago:

In July 1826, if my memory has not failed me, a lightning struck the house of my friend and colleague in Altona, where I used to practice as a doctor. The house is situated 100—120 feet above the Elbe River. My friend, Dr. Van der Smissen, was walking up and down his room, when he

suddenly heard a thunderclap. At the same moment a fiery mass appeared on the floor of the room; it moved close to the wall in the shape of an egg-shaped ball, whose size was roughly that of a hen's egg; it then crept along the wallboards, which, as is common in our town, are varnished. With the quickness of a mouse it sped toward the open door, jumped with a loud crack onto the banister of the staircase, which led to the ground floor, and disappeared without leaving a trace.

7. June 1829, Montmouth. Sestier. De la foudre, de ses formes et de ses effets 1, p. 138.

During a thunderstorm in June 1829 three persons were sitting in the kitchen of an inn in the vicinity of Montmouth, when they suddenly heard two violent thunderclaps and shortly thereafter saw a fireball the size of a cricket ball and crimson red in color enter via an open backdoor. They
22 witnessed the ball traverse the kitchenfloor, pass into a corridor and finally leave the house via the frontdoor. The meteor neither caused damage to the building nor bodily harm to those present.

8. Summer 1837. 2 p.m. Department of Mosel. Arago 4, 41.

Letter of the landowner Hapouèle to Arago:

At about 2 p.m. on a hot summer day of the year 1837 (I do not recall the exact date) I was standing in front of the door of my stable, which is covered by a roof; opposite to me stood a dwelling, the door of which was left open. Between this building and myself lay a large manure pit.

Suddenly, with a fearful thunderclap, I saw a luminous ball the size of an orange plunge obliquely toward the middle of the manure heap about 40 feet away from me. I thought it was going to penetrate into the manure, but as it approached to within 3 feet of the heap it assumed a perfectly horizontal trajectory parallel to the ground and moved toward the door, which my wife had just closed.

As soon as the ball approached the house to within 50 feet it ascended toward the clouds at the same oblique angle as when it had plunged down; in doing so, it passed the highest roofrim of the house at a distance of about $1\frac{1}{2}$ feet. At a height of 160 feet I lost sight of the ball.

9. 28 August 1839. Paris. Am. Guillomin, Le monde physique 3, 429; 1883.

On 28 August 1839, in the middle of a violent thunderstorm, whose black and heavy clouds nearly touched the rooftops of the buildings, a thunderbolt struck the center of the courtyard of the not yet completed central revenue office of Paris. This lightning took the form of a fireball and was followed by a trail of vapor; it smashed into the ground, which consisted of fresh earth, and hollowed out a groove about 18 cm in diameter; there it spinned violently, lifted up the loose earth, and then leaped up, only to fall back again about 3 meters farther, where it made a new hole 9 cm in diameter, while continually carrying out violent movements. Soon thereafter the fireball jumped out of this hole onto the surrounding wall, along the top of which it rolled a distance of about 30 meters. Upon arriving at the corner of the wall adjacent the St. Louis Hospital the size of the ball had already decreased and it fell onto the wet pavement, moved along a long
23 curved path, passed through the gate of the hospital and disappeared in

the middle of the courtyard opposite the church. The ball became smaller as time passed; when it arrived at the center of the courtyard of St. Louis Hospital, it was no larger than a thin, slightly luminous strap, which all of a sudden disappeared. The instant the fireball fell into the courtyard of the city revenue office all workers and other people who had taken safe shelter in the vicinity felt a lively electrical shock, and all suffered from the remaining pungent sulfur odor.

10. June 1841. 6 p.m. Mailand. Comptes Rendus 35, 193—194, 185.

Extract from a letter of Buttis, marine painter of the Empress of Austria, of Trieste to Arago.

In the year 1841, and if my memory has not escaped me, in the month of June, I stayed in Mailand in the inn at Lamm; I had a room on the second floor which has a view of the Corsa dei Servi. It was about 6 p.m., the rain was pouring down and lightning lighted up the dark room more brightly than gas flames. Intermittently dreadfully cracking thunder was heard. The windows of the house were shut and the street deserted, since the rain, as we mentioned before, was pouring down in streams and had transformed the road into a rushing brook. I was quietly sitting in my room, smoking a cigar and watching the rain, which sparkled like golden threads in the sunlight, at a distance through the open window of my room. Suddenly I heard several children and adults on the street shouting: Guarda! Guarda! (look! look!); at the same moment I heard a noise like that produced by several spiked boots. Since I had not heard a human voice for the last half hour, this tumult attracted my attention. I hurried to the window and glanced to the right from where the noise came. The first object that caught my eye was a fireball, which moved not along a horizontal but rather a slightly inclined path down the center of the street at the height of my window. About 10 people among the crowd were shouting Guarda! Guarda! and followed the ball down the street at a pace which is known by soldiers as the forced march. The luminous ball moved quietly past my window, so that I had to turn my head to the left in order to see how this remarkable phenomenon would end. A moment later, when it threatened to pass out of view behind the houses standing directly opposite my room, I hurried out into the street and arrived in time to still catch sight of it and join the inquisitive crowd. The ball was still moving just as slowly as before; however, it was at a greater height, since, as mentioned before, it followed an upward sloping path; after about 3 minutes it reached the cross on the steeple of the dei Servi Church and then vanished. The disappearance of the ball was accompanied by a heavy explosion, similar to that produced by a 36-pounder, when heard under favorable wind conditions at a distance of about 15 miles. If I were to describe the size and color of this fireball, then I can compare it only to the moon, when it rises on a clear night during the winter in the Alps, such as, for example, I recall seeing in Innsbruck in the Tirol, namely a reddish yellow disk with several spots. However, there was a difference in that the contour of the ball was not sharply defined as in the case of the moon; it seemed much more as if it were enveloped in a luminous atmosphere, whose dimensions could not be reliably specified.

11. 24 August 1842. 10 a.m. Ille. Sestier. De la foudre, de ses formes et de ses effets 1, 139.

12. 12 September 1845. 2 p.m. Salagnac (Creuse). Sestier. De la foudre, de ses formes et de ses effets I 139, II 234 after Maslieurad Lagemard.

On September 10, 1845, at about 2 p.m. a thunderbolt struck a house in the village of Salagnac (Creuse) during a violent storm. With a very loud thunderclap a sparking fireball about the size of a fist plunged down a chimney and dropped in the midst of a child and three women; without causing them any bodily harm it turned toward a wooden cabinet for table utensils from which it tore off several pieces; it then reached the middle of the kitchen, traversed the latter in a straight line, passed by the feet of a young man standing there, but did not strike any of the iron pots. Instead it entered a neighboring room and vanished without leaving the slightest trace. The women, who witnessed how the ball slowly traversed the kitchen, motioned the young man to step on the fireball in order to extuinguish it. The young man, however, had enough sense to remember that during a stay in Paris he had several times amused himself at the Champs Elysées by letting himself be electrified. As he compared the electric shock he had suffered at the time with that he expected from the fireball at his feet, he was wise enough to let the ball pass by. The fireball left a trail of dense smoke having the smell of sulfur. A pig, which had been kept in a small sty, was found dead. Dr. Maslieurad Lagémard established that complete decomposition had set in after 3 hours. The lightning had passed through the hay without setting it afire.

13. 30 June 1847. 5.10 p.m. Châtre (Indre). Comptes Rendus 25, 85, 1847.

14. 16 June 1850. 6.30 p.m. Paris. Comptes Rendus 35, 192 — 193, 1852.

Letter of Mme. Espert to Arago.

A short newspaper article by Mr. Meunier on the effects of ball lightning has led me to inform you about a similar meteorological phenomenon which I witnessed.

I live at No. 1 Cité Odiot on the second floor which provides a view of the Beaujou estate. It was in July 1849, the 16th I believe, a Friday, about 6.30 in the evening of the same day on which the cholera outbreak in Paris had reached its peak. The air was suffocating and the sky seemed quite calm; however, lightning flashes could be seen from all directions. As I was passing the very low window of my room my eye suddenly caught sight of something that looked like a large red balloon. In fact, it looked exactly like an enlarged moon covered by mist. This balloon slowly dropped vertically onto a tree standing in the Beaujou estate. My first thought was that I was witnessing a balloon ascent by the Brothers Grimm; however, the color of the balloon and the time of day convinced me that I had erred. While I was wondering what this could be, I saw how the bottom part of this ball, which hovered about 16—22 feet above the tree, suddenly caught fire. It could have been compared to paper which burned slowly with small sparks and flames. When the opening reached about three

times the size of a hand, a sudden, frightening detonation burst the entire outside cover and the hellish machine within ejected a thousand zigzag-shaped lightning streaks in all directions. One of these struck a house at No. 4 Cité, where it made a hole like that of a cannonball. The hole is still there. Finally, the rest of the electrical matter began to spark with white, lively and bright flames and to revolve like a spinning sun in a fireworks display. The phenomenon lasted longer than a minute. It offered such a beautiful sight that at no time the thought of danger or fear crossed my mind; I could only exclaim: Oh, how beautiful! Oh, how beautiful! The detonation was so violent that it knocked over three people on the street and, as you can well imagine, caused pandemonium in the Cité and the entire city quarter. My cook was nearly frightened to death by one of the lightning streaks that passed the window. The landlord's wife dropped a key which she was holding in her hand; however, she was not sure whether this was due to fright or to a shock produced by another lightning streak, which passed down the front steps as she was standing on the landing. Another lightning streak struck into the boarding house of Mme. Loiseau, Rue Neuve de Berry, and wounded one of the governesses. The inhabitants of the house at No. 4 ran terrified into the courtyard; no one, however, suffered any bodily harm.

All of Paris talked about this tremendous explosion; however, I am perhaps the only person, who, quite by accident, observed the phenomenon which caused this detonation, and I might even say that I would not have missed seeing such a wonderful and extraordinary spectacle for anything.

15. 6 January 1850. 6 p.m. Ecquevilie near Meulan. Sestier 1, 128.

16. 17 May 1852. 5 p.m. Beuzeville (on the Paris—Le Havre railroad). Comptes Rendus 35, 24 and 400, 1852.

Communication of Labande concerning his investigations of the rumors of 17 May in Beuzeville and surroundings:

On 17 May shortly before the departure of the combined passenger and freight train No. 18 a few minutes after 5.00 p.m., at which time a violent thunderstorm broke loose over Le Havre, the telegraph posts at Beuzeville, 202 km from Paris, Barentin (158 km) and Malaunay (149 km) suddenly received a communication from Le Havre (228 km) that they were to ground the telegraph wire and switch to direct communication. Now, was this message improperly despatched at Le Havre, was it disregarded or misinterpreted at Beuzeville? It would be very interesting to know the answer to this question, but unfortunately I cannot elaborate on this at all.

I will merely describe the atmospheric processes as they were related to me by an eyewitness, in whom I have the fullest confidence, or even better, I will let the stationmaster Maillot (formerly a chief forest ranger), a mature man with common sense, good power of judgement, and incapable of being alarmed without good reason, describe the happenings in his own words:

After my wife had taken my place at the telegraph booth, I made my way to the other side of the sloping railroad tracks next to the supply shed in order to speed up the loading of a freight car with gypsum which was to be hooked up at 6.18 p.m. to the combined passenger and freight train to Paris. As the despatcher Heuzé was expressing his regret that he had only straw

instead of a tarpaulin to cover his goods, I perceived directly ahead of me toward the southeast a luminous ball, to which I drew his attention. At the same time I instinctively summoned at the top of my lungs a baggage master by the name of Hilaire to join us in witnessing this spectacle. Thanks to my timely call he saw just as clearly as Heuzé and myself that the luminous bomb, which, as we assumed, would pass over our heads, came to a stop instead and suddenly vanished above the telegraph wires at a distance of about 20 meters from us. At the same time the lightning struck, as it turned out later, the Beuzeville cemetery. This led me to believe that the zigzag path the luminous ball seemed to follow as it approached us was nothing else but a manifestation of lightning. The electrical phenomenon was preceded by light rolling thunder. A heavy downpour followed which lasted at least 10 minutes. However, the thunderstorm broke loose with greater force over Criquetot-lès-Nesval, where extensive damage due to hail was caused.

Mrs. Maillot, who, as previously said, was left at the telegraph booth, told what had happened the moment she heard her husband calling Hilaire. There was loud interference from the Breguet apparatus which was standing about 1 m behind her. As she turned around upon hearing a peculiar crackling noise, which seemed to come from the tapping key to which the leads are connected, she clearly saw numerous sparks coming out of a small hole, a type of light which spread to the manipulator at the base of the telegraph system. She also showed me a screw, which served to fasten the brass wire connected to the telegraph dial. She claimed that this screw was dislodged due to the tremendous shock, which seems very strange to me, since the device was set up in such a way that the electric currents could be shunted to earth. Is it not more probable that Mrs. Maillot, who was working in the absence of her husband, had unintentionally connected herself to earth by accidentally touching some component of the device, or that at the moment in question she had unknowingly connected the switches, to which the telegraph wires lead, to the receiver? This presumption would lead to the supposition that as the lightning struck the Beuzeville cemetery 2 km away, it hit the electric wire, penetrated into the building, followed the wires, which connect the line with the magnet needle, and from here to the tapping key, the receiver, back again to the manipulator and finally to earth. Assuming that the lightning followed this path, then we can understand to some extent the sparks, which were observed at the magnet needle, the pointer of the receiver and the pivot of the manipulator. Further, in order to explain that the latter had produced sparks, it must be assumed that the crank had been turned or had received a strong jolt, since the manipulator is directly connected to earth via metal wires which pass through the wood.

The crackling heard by Mrs. Maillot must have been produced by the receiver, whose pointer during any kind of lightning can be displaced one or more terminals forward, so that in the special case of Beuzeville it could have effected a fairly versatile oscillatory movement.

An account concerning the same lightning event was reported to Pouillet by the manager of the Rouen railroad.

I will attempt to relate as accurately as possible what I learned upon questioning an eyewitness, whose recollections of the event seemed very vivid to me.

On May 17 of this year the stationmaster of Beuzeville received from Le Havre a telegraph message to the effect that owing to a raging thunderstorm the telegraph equipment was to be grounded. This he did, even though the thunderstorm was nowhere near Beuzevillie. Shortly thereafter a strong wind began to blow and dense clouds started to form. Since not a drop of rain fell, the stationmaster believed that the thunderstorm would pass over and break loose somewhere else. He thus carried on supervising the loading of the freightcar, which was due to be hooked up to the next train. Just at this moment (it was somewhat after 5 p. m.) three loud thunderclaps were heard at short intervals. The third crash was accompanied by a thunderbolt which struck behind a farmstead about 1 km from the station. The place where the shining and violent discharge struck the ground was hidden by trees. However, at the same moment a fireball, which was apparently the size of a small reddish brown grenade, leaped up from behind the trees. It described an elongated path, was followed by a vivid trail of light, moved with moderate speed, so that it could be easily followed by the eye, and apparently seemed to move along an arched trajectory in the direction of the station. The motion of this ball and the bright luminous trail were similar to that produced by flares during night-manoeuvres.

It was astounding when the fireball, instead of passing over the station, settled like a bird on the telephone cables at a distance of about 100 meters from the station. At the same moment the ball and all the light vanished with the speed of a thought crossing one's mind. It left no traces on or below the wires. However, at the station the stationmaster's wife, who at the time was preparing the tickets, witnessed the following phenomenon: the apparatus started to emit a very lively crackling sound, the pointers oscillated madly with a shrieking tone, like that produced by a turnspit when suddenly released, or by a grinding stone when grinding a piece of iron. One pointer, that of Rouen, snapped off; all screws in this part of the apparatus were loosened, and on the copper dial next to the pivot of the pointer a hole was seen which was large enough for a kernel of wheat to pass through. The other part of the apparatus suffered no damage and the pointer of Le Havre maintained its regular trend; its dial, the screws, etc., remained untouched and no sulfur odor was perceived.

This thuderclap was followed by a heavy downpour; thereafter nothing of special interest happended.

The stationmaster's wife was terrified, but experienced neither shock nor any other physical effect. Her husband was convinced that had he not grounded his apparatus the lightning would have caused violent effects in his office.

This concludes, my dear colleague, all my findings on this particular manifestation of lightning. Its reddish brown, somewhat dull color as compared to the bright luminous trail, the smooth, arched trajectory which it described, the sudden stopping of the fireball above the telegraph wires, on which it seemed to settle like a bird, are all facts which have been repeated to me several times and which were related accurately and in detail by an elderly man, an ex-serviceman, of solid and sound character, and his wife, who has too critical a mind to let herself be carried away by what she had seen and felt.

17. June 1852. 11 a.m. Paris. Comptes Rendus 35, 195, 1852. From a letter of Meunier, office head in the Ministry of the Interior, to Jamin, who in turn communicated the extract to Arago (see also Arago IV, p. 48).

18. July 1854 or '55. 9 p.m. Brünn. Verhdlgn. nat. Ver. Brünn 36, 41, 1897.

19. 8 June 1859. 1.20 p.m. Argenteuil (Seine and Oise), Cosmos Revue des Sciences 14, 672—675, 1859.

20. 1859. Waterneverstorf (Plön). Weber. Berichte über Blitzschläge in der Provinz Schleswig-Holstein. 2nd Issue 1885.

21. 19 February 1860. Evening. Roleghem near Courtrai. Le Cosmos 16, 281, 1860.

22. 8 June 1861. 1.30 p.m. Bouin (Loire). Cosmos 18, 1st Sem., 758—759, 1861.

23. 10 September 1861. 3.30 p.m. Montélimart Station on the Marseille — Lyon Railroad. Comptes Rendus 53, 646.

During a railway journey from Marseille to Lyon a gentleman by the name of Sacc made the following observation, which he communicated later on the same day to another gentleman; the latter submitted the letter to the Academy of Sciences:

Just before Montélimart we ran into a downpour. The hills of Montélimart were covered by heavy clouds, from which yellow lightning flashed with such regularity that the subsequent thunder gave the impression of a light-artillery barrage. Twice I saw the lightning strike the ground closer than 100 paces from the train, which was slowing down as it approached the city. We were situated right below the heart of the thunderstorm, and in realizing the inherent danger I kept my eyes fixed on the seven telegraph wires. Suddenly, at about 3.30 in the afternoon, our carriage was shaken by a violent jolt; I felt something like a strong gust of wind on my right check; an intense howling caused all the passengers to jump to their feet, and at the same moment I heard a loud discharge like the report of a pistol. I saw a red fireball the size of a fist which slid along the upper telegraph wire and then dropped successively to the other six wires and finally plunged toward the ground. The upper third portion of a wooden telegraph pole, somewhat further away, was struck and smashed to splinters, as if an explosion had occured within the pole. The broken portion was left dangling on that part of the pole which remained upright and still held the seven wires on the Lyon side which were apparently undamaged. It seemed strange to me that the seven porcelain insulators were still attached to the broken portion. Is that possible?

24. 2 August 1862. 11 p.m. Paris. Cosmos 21, 141, 1862, 2nd Sem.

25. 30 August 1865. 4.30 p.m. Feistritz near Peggau in Steiermark. Sitzber. Math. — Nat. Kl. der K. Akad. d. Wissensch. Wien, 58, II, 1045—1048, 1868.

26. February, first half of 1866. 6.30 a.m. La Chapelle-Largeau. Cosmos, 2nd Ser., 3, 199—200, 1866.

27. Spring 1866, Eisleben. Observed by Geh. Stud.-Rat Direktor Dr. Knabe.

In the spring of 1866, at which time I was a sixth-grade boy in Eisleben, I witnessed a ball lightning. I was in a room, whose window provides a view of a country road which passes the house at a distance of about 10 m. In the afternoon during very hot weather a thunderstorm broke loose. Suddenly I saw a fiery ball about the size of a head moving relatively slowly parallel to the road at a height of approximately 3 m. I do not recall whether a crash of thunder preceded or followed the event. This fireball then ascended at a distance of about 20 m from where I was standing to the edge of the roof of a shed, climbed up this roof, moved a little forward on the top portion of the roof, smashed through the roof at two places, united again, flew at low level over the ground through the open door of the shed between two workers and extinguished itself in a water puddle inside the shed. I did not observe the subsequent path of the ball lightning, but directly established this by examining the traces along the ground and by questioning the workers. Except for the clatter of the shattered tiles and boards on the roof, neither the men nor I heard any explosions. The entire phenomenon made an uncommonly harmless impression.

28. May, 1860's. 12—1.00 p.m. Ellwangen. Sauter. Progr. Ulm 1892. p. 20.

Captain Schabel of the 13th Foot-Artillery-Battalion in Ulm was kind enough to communicate the following report to me: from what I remember I can tell you the following about a ball lightning I observed: "It was in the 60's on Ascension Day between 12 and 1 o'clock in Ellwangen; the weather was warm, the sky overcast, but there was no sign of a storm. I was on
32 the street, when suddenly a dazzling lightning and a thunderclap following immediately after indicated that the lightning must have struck somewhere. Since the collegiate church was close by, I first looked in its direction and then saw how two diverging fiery balls moved at a moderate speed from the foot of one of the steeples across the market place toward me. Both balls were approximately the size of a skittle ball and emitted a bluish light. The first thought that crossed my mind was to make way and I thus fled into the nearest house. A while later, when I stepped out onto the street again, there was absolutely nothing to be seen and no signs of a thunderstorm could be recognized. Insofar as I know, not a single person was in the street at this time, since it was lunchtime. When I subsequently related this phenomenon I was met everywhere with disbelief.

29. May 1868. Evening. Bruchsal. Das Wetter, 17, 191.

Motivated by an article in the "Gartenlaube" on ball lightnings, I would like to inform you of an observation which I made about 32 years ago and bears relevance to this problem: It was on an evening in May, when I, a

nine-year-old boy at the time, was on my way to May Service at the Catholic church in Bruchsal. Since a fairly heavy thunderstorm was gathering, I stopped to stand in one of the gothic niches, which form covered esplanades at the entrances to the church, in order to observe the course of the thunderstorm. After several intense lightning flashes, which were accompanied by violent thunder, I suddenly saw after a further lightning stroke a glowing white ball the size of a large billiard ball near the church spires; it descended slowly in somewhat zigzag fashion and hovered for a short time at the height of the belfry, whereupon it slowly entered the tower horizontally (perhaps it was attracted by the metal bells?) and disappeared from sight; a few seconds later a bell rang as if struck by a hard object and several seconds thereafter the fireball glided horizontally out of the tower and once again descended in slightly zigzag fashion toward the place where I was standing; at a height of about 5 m above ground and approximately 10 paces away from me the ball came to a stop; after a few seconds it finally descended toward the pavement, which in the meantime was already quite wet due to the rain, and upon touching the ground it made a crackling noise, disintegrated into sparks and, as far as I could tell, vanished without leaving a trace. I then quickly ran to the spot to see if any pieces of the ball were left on the ground, but found nothing at all; I could not even detect any strange smell. This concludes my account of the event, which is firmly embedded in my memory, and which I hereby humbly put at your disposal in the name of science.

30. August 1868. During the day. Near Arnsberg. Das Wetter 6, 68, 1889.

In August (?) of the year 1868 I was engaged in the construction of a tunnel on the Upper Ruhr Valley railroad in the vicinity of Arnsberg. One day during a thunderstorm we took shelter under the roof of the nearby blacksmith and wheelwright shop; the shelter provided by the roof against the downpouring rain was not too good, since the roof had leaks at various places.

The sun was already shining again for some time and only a few, fairly transparent clouds could be seen in the sky. We had already forgotten the storm and were even less occupied with the thought of another thunderstorm. The four of us were busy on the trestle and were just about to lift a stone plate approximately 80 cm square onto the wall; we were standing in a circle, suspecting nothing, when suddenly a lightning flashed and a round, yellowish, transparent ball of about 20 cm diameter appeared in our midst at approximately 90 cm above the stone we were about to lift onto the wall; the ball oscillated continually about 4 cm up and down above the plate. At the center of this ball there was a blue flame, which was pear-shaped with the tapered portion slanted downward and had a length of 4 cm. This flame rapidly rotated around a vertical circle of about 7 cm diameter inside the large ball. Anyone can imagine how startled we must have been. My eyes were fixed upon the frightful intruder and my only thoughts were how to get rid of it. However, I shall not waste time elaborating about this. After about 3—4 seconds there followed a loud bang, such as I had never heard before, and the ball vanished, none of us knowing where it had gone. However, we breathed more freely now and I felt as if the full load of the heavy stone which lay before our feet had been taken off my shoulders. When we recovered from the shock and lifted the stone onto the wall our limbs were almost paralyzed.

The wheelwright, who was working on the roof about 10 m from the site of the event, did not notice the ball, but upon nearing the detonation slipped, either because of fright or the shockwave, and fell off the roof without suffering any injury. Immediately thereafter we were informed that lightning had struck a quarry about 100 m away.

The editor in chief of "Das Wetter" added: considering the rarity of cases whereby ball lightning is clearly observed, it seems appropriate to publish earlier accounts of this phenomenon, provided that they were given by trustworthy persons. The above description originated from chief mason Emde of Brilon and amply fulfills the said prerequisite concerning the meteorological observations made. The same view was put forward by the "Sauerländer Anzeiger."

31. 20 October 1868. 5.15 p.m. Vienna, Sitzber. Math.-Naturw. Kl. der K. Akad. d. Wiss. 58, II, 761—769, 1868. (With figures.*) (Abbreviated.)

..... The electrical fireball was one of the first discharges of the thunderstorm of October 20 between 5.15 and 5.30 p.m. The fiery phenomenon followed, according to deviating accounts, 6 to 20 seconds after a weak, not very persistent thunder. Later, several discharges followed; it was also learned that lightning had struck in Nussdorf. After the onset of the electrical discharges hail and rain followed. The description of the phenomenon hardly credits the impression it made. I hastened to draw a sketch of the mass, which in itself was a fairly simple task, but I also attempted to incorporate the colors involved. The ball can be readily described; it emitted a vivid yellow light primarily on the right (toward the west side), while on the left (toward the south side) a definite red color prevailed; in addition, long red, green and dazzling white streaks shot out of the ball toward the right and downward. Also toward the left emanated shorter streaks, which slanted toward the ground. The impression left by the phenomenon, the sketch of which inevitably falls short of reality, is much more vivid than the above description. The picture also shows the site at which the meteor was observed. It stopped perhaps 2—3 seconds just in front of the right-hand pane of the window. Only this portion was exposed to observation. The blinds covered the upper portion, while the lower portion was hidden from view by the roof of the house at No. 4.....

32. 1868. Baireck near Schorndorf (Württingen). Sauter. Supplement to the curriculum of the Royal Realgymnasium at Ulm. 1891—92.

33. 13 July 1869. 7.07 p.m. Island on the Rhine near Kehl. J. Müller. Kosmische Physik, p. 806, Braunschweig. 1894.

On 13 July 1869 toward the evening a thunderstorm without rain approached from the southwest. At 7.07 p.m., with a frightful crack, lightning struck a poplar on the island near the Kehl pontoon bridge. Immediately thereafter an electrical fireball moved from the area of the poplar in horizontal fashion toward an 840-m-distant chestnut tree near the customs house; upon arriving at this tree it vanished with an explosion. The fireball, which was seen by

* A reproduction was not possible due to the costs involved.

several reliable eyewitnesses, who compared its size to that of a cannonball, covered the distance of 840 m between the poplar and the chestnut tree in 3.5 seconds. The ball lightning, which struck the chestnut tree, penetrated via the trunk into the ground; however, part of the lightning also struck three soldiers of the French guardpost who were sitting on a bench under the tree. Two soldiers were killed instantly, while the third was seriously injured.

34. December 1870. 5 p.m. Latium. Atti della Pontif. Accad. Rom. dei Nuovi Lincei, 66, 57.

35. 31 December 1870. 5 p.m. Rome. Atti della Pontif. Accad. Rom. dei Nuovi Lincei, 66, 58.

36. End of June 1874. 9—11 p.m. Schöntal near Mochental. O.A. Ehingen. Sauter. Supplement to the curriculum of the Gymnasium at Ulm, p. 20, 1892.

Head gamekeeper Mehl from Mochental was kind enough to inform me of an observation of ball lightning:

"I was on an evening hunt on the Schöntal preserve after a very hot day toward the end of June 1874. At about 9 p.m., on my way back home, I was suddenly taken unawares by a very violent thunderstorm, which forced me to seek shelter in an old wooden cabin directly situated on a narrow macadamized road. While the storm was raging with unbelievable force, I noticed bluish-colored balls, which were rolling about on the road outside and burst into a crackling spray of sparks partly in front and partly behind the place where I was standing. The size of the balls corresponded to that of an average size skittle ball. The bursting of these balls which took place several times in my direct vicinity (so th . I could very clearly see what was happening) did not cause any loud detonation, but instead such a dazzling light that I was momentarily blinded. The speed at which the balls traveled was not very great, no greater than that of a firmly cued skittle ball. These balls moved in the same direction, all the time following the course of the road, in varying time intervals (at times in rapid succession); in a period of half an hour I counted 25—30 of these balls. The thunderstorm descended upon a basin-shaped forest complex, where it raged at full force for two hours. The ball lightnings appeared at the very beginning of the thunderstorm, while the rain was pouring down and ordinary lightning streaks accompanied by rolling thunder were coming down from all sides and struck several times in the vicinity of the cabin. Since I dared not go out onto the road, not because of the ball lightning but because of the ordinary lightning discharges which were striking the high trees along the road, I stayed inside the old hut until the storm died down, which was at about 11 p.m. I was happy, when I could finally leave the clammy hut without having suffered any injury. Ever since, I have had neither the opportunity to observe any more ball lightnings nor the desire to stand once again in the midst of a grenade fire, such as took place on that night.

37. Summer 1874. Afternoon. Aurich. Das Wetter, 30, 286.

38. 24 July 1876. 3.30—4.00 p.m. Paris. Comptes Rendus 83, 321, 1876.

39. 18 August 1876. 7—8 a.m. Paris. Comptes Rendus 83, 478, 1876.

40. 7 October 1876. 5—6 p.m. Sidney Harbor. v. Urbanitzky. Die Elektrizität des Himmels und der Erde, p. 432. Vienna, Pest, Leipzig. 1888.

On 7 October 1876 during a thunderstorm at about 5 or 6 o'clock in the evening the author of the report, J. Formby, was on board a small steamboat in the harbor of Sydney, when suddenly a vivid yellow fireball of 7—8 cm diameter landed on the deck. It rolled a distance of 4—5 m, penetrated the canvas and exploded amidst a group of ladies. Formby was standing nearby with two friends and quickly went to see if any accident had happened. However, no one was injured and neither traces of the path of the fireball nor holes or burned objects were found. The place at which the ball landed on the wet deck was dry. At the time of the explosion there followed a loud thunderclap.

41. 21 March 1877. Noon. Vence (Southern France). Comptes Rendus 84, 666, 1877.

42. June 1877. 4 p.m. Paris. v. Urbanitzky. Die Elektrizität des Himmels und der Erde. Vienna, Pest, Leipzig. 1888, p. 436.

It was in the month of June 1877; a servant of the house at No. 82 Rue d'Assas in Paris was sitting on the garden veranda. It was a very stormy day and the sky was overcast, but it had not rained. The atmosphere was stifling and forecasted thunder. At about 3.30 p.m. the sound of distant rolling thunder was heard. At 4 p.m. the servant, who had remained on the veranda, let out a cry upon seeing a fireball somewhat larger than a head. It seemed to consist of burning sulfur and emitted blue flames. The ball slowly descended toward the garden, hovered a few moments like a soap bubble above the lawn, then suddenly ascended with much greater speed than when it had come down. It flew over the house and then hit a pillar in the Rue de l'Abbé de l'Epée about 100 m from the Rue d'Assas. At the same moment a loud detonation was heard. An examination of the sidewalk at the place where the ball had landed showed that the asphalt was torn apart and several chunks were hurled a large distance away. The resulting hole was a foot deep and 50 cm in diameter. The event was followed by a heavy hailstorm.

43. 24 July 1877. Noon. Österdamnen Manor near Hjönring (Jütland). Gäa. 13, 565—566.

In Denmark the 24 July 1877 was marked by a large number of exceptionally violent thunderstorms. Especially in the evening a thunderstorm such as there had never been before broke loose over nearly all of Denmark. Among the many lightning flashes, which in the course of the day had partly resulted in the loss of human lives and which were widely covered

in the newspapers, one case is of particular interest. The thunderbolt in question was observed at Österdamnen Manor about one mile south of Hjörring in Jütland, and, according to the local newspaper, seemed to be the result of a ball lightning. The owner of the manor, Mr. J. Räbild, gives the following account: "Already on the morning of the day in question we heard a violent thunderstorm in the distance which toward noon came closer, but not close enough to cause alarm. At noon, without suspecting
8 anything, we sat down at the table, when we were suddenly almost paralyzed by fright owing to the presence of a fireball the size and form of a human head and reddish-yellow in color, like the moon on a dark October evening, but somewhat brighter. The ball, which emitted an intense light to the surroundings, entered via an open door five ells away from the window of the room in which we were sitting; it smashed into the plaster, burst into pieces as if it had exploded and vanished at the same instant. It was accompanied by a fearful crack and hissing, which caused everything in and around us to shake; it likewise ceased just as suddenly as the fireball. At the same time dense bluish smoke came out of the door from the fireside inside through which the fireball probably entered. This was borne out by the fact that at the bottom of the chimney, which is open, as well as along the stone floor we found a quantity of ash and soot which was probably entrained by the air current. The ball had followed this path without bumping into any objects. The adjoining rooms were likewise full of smoke, which smelled like gun powder and was so strong that it rendered breathing troublesome. Otherwise, I could not detect any effect of the explosion or traces of fire, with the exception of a stone in the chimney which was slightly loosened. I have no idea about the initial direction and speed of the fireball, and when I had asked several people to this effect, no one had seen anything, though some did hear the strange muffled and hissing noise, which stopped so suddenly. At the time the lightning struck there was no downpour, but merely a slight drizzle and a few minutes later the sun shone again. After the appearance of the fireball, lightning was neither seen nor was thunder heard until 5 p.m., when a violent storm was moving in our direction. The extremely heavy thunderstorm in the evening was, of course, also observed here.

44. 23 July 1878. 2 p.m. Southampton. The Americ. Journ. of Sc., 151, 4th Ser. 1, p. 13.

45. 10 August 1831. 3 p.m. Barbados. Dove. Klimatologische Beiträge VII. Über das Gesetz der Stürme. Berlin 1857, p. 221. (At the time of the famous hurricane.)

..... The lightning flashes ceased for a few moments and the darkness,
39 which now enveloped the city, was inexpressibly hideous. Fiery meteors were now falling out of the sky; one of these was spherical in shape and dark red in color, and came straight down from a considerable height. This fireball fell under the sole influence of its weight, i.e., it was not driven by some external force. As the ball accelerated toward earth it became dazzling white in color and oblong in shape. Upon hitting the ground in Beckwirth-Square it spattered about like molten metal and died out immediately. Its shape and size corresponded to that of a lampshade and the spattering about upon contact with the ground reminded one of drops of mercury.

46. 5 May 1881. 4 p.m. Vegesack near Bremen. Abhdlg. Nat. Ver. Bremen 11, 314—315, 1889.

47. 24 May 1881. 8 p.m. 57°34' lat. S and 69°40' long. W (SW ½ S 124 naut. mi. from Cape Horn). Ann. Hydr. 10, 582, 1882.

During the voyage from Hamburg to Valparaiso on 24 May 1881. At 8 p.m. we ran into a dense snowstorm. I just happened to be in the cabin, when I suddenly noticed a bright light on deck. At the same time I felt as if all my limbs were electrified. I immediately dashed to the deck and arrived in time to see how a glowing ball about ½ m in diameter fell into the water at approximately 2.5 m off the port side between the main mast and the mizzenmast. A terrifying detonation was heard right after a heavy burst of thunder. The second coxswain and the man at the helm were complaining about their eyes; both men were blinded for several minutes. Two sailors, who had been standing on the foredeck, came running abaft and claimed that they had just been struck by lightning. — The ball plunged straight from the zenith and fell somewhat toward the east. At the time the wind was westerly, strength 7. Just before all this happened, when I was checking the temperature, I noticed an extraordinary thing, namely that despite the snow several stars could be seen in the zenith. As the ball came falling down a remarkable heat wave was felt. Two minutes after the detonation we noticed St. Elmo's fire on all three mast tops as well as on the ends of the topgallant and royal spars. After the event the wind increased to strength 8 and the snow changed to rain ... According to data in the meteorological journal it seems that the ship was situated in the vicinity of a secondary depression, when the ball lightning (it can be assumed that such was the case) was observed. Already at 7 p.m. lightning flashes were observed during a hail and snow shower.

48. 13 July 1881. 2 a.m. Bremen. L. Häpke. Merkwürdige Blitzschläge. Abhdlgn. Nat. Ver. Bremen 11, 316, 1889.

49. July 1881. 4—5 p.m. Hermsdorf in Silesia. Met. Zeitschr. 4, 171, 1887.

50. 31 May 1882. 5 a.m. Calais. Courrier de Pas-de-Calais of 1 June 1882. Translated in v. Urbanitzky: Die Elektrizität des Himmels und der Erde. Vienna, Pest, Leipzig 1888, p. 438.

At 5 o'clock in the morning lightning struck the Veret's dairy in the Rue des Chauvines. Mme. Veret, who was busy milking a cow in the stable, witnessed how a fireball entered the stable, passed through the space between a cow and the wall (this space could not have been wider than a foot) and finally left via the door without leaving a trace or causing injury to any person or animal. The fireball moved slowly at all times and took several seconds to cover the path it followed. Two persons witnessed the phenomenon.

51. 5 July 1883. 1.30 p.m. Malma near Upsala. Met. Zeitschr. 2, 118, 1885. (See also the somewhat modified version in Z. d. österr. Ges. f. Met. 18, 385, 1883).

On 5 July 1883 in the village of Malma near Upsala the rare phenomenon of ball lightning was observed. At about 1.30 in the afternoon, following lightning and thunder, the discharge burst into the kitchen of a farmer's wife, or more precisely, through a vertical crack of 3.5 cm width next to the window. The phenomenon, which was egg-shaped and about 50 cm long, slowly descended with the tapered end pointing upward toward the floor without touching the latter. Since the door was closed, it lifted itself and disappeared through a horizontal opening of 14 cm length and 3—4 cm width about 1.5 m above the floor. Immediately thereafter, several detonations similar to a volley of riflefire were heard. These were so loud that all the neighbors came running, without, however, seeing anything further. A tailor, who was sitting next to a window in another house had seen the ball as it descended from the clouds to the window; possessed with fright he ran away from the window and saw nothing else. Mr. Hildebrandsson could not detect any traces of fire at the site in question. Only a few toys, which were standing on the window ledge, were knocked over and at the exit some moss, which grew in the opening, was thrown outside, but was not burnt, despite the fact that it was dry. The thunderstorm and the
41 wind came from the east, namely, the side on which the window, through which the ball lightning penetrated, was located; thus, the ball apparently followed the air draft toward the adjacent floor opening on the west side. The size of the phenomenon was hardly exaggerated by the two women, who were in the kitchen with two children, since the small girl asked right away: "Mama, did you see whether the golden man had feet?"

52. July 1883. 4 p.m. Wolfhagen (Hessen-Nassau). District Judge Wagner

During a very heavy thunderstorm a ball lightning moving in the direction NS was observed through a window. Prior to the event it had rained very heavily; the clouds were at medium altitude. The size of the fireball corresponded somewhat to that of a skittle ball. The speed at which it traveled was as if it had been hurled. It passed at a height of 12 m above the ground at a distance of 15 m from the house. It vanished with a deafening detonation and left the impression of a glowing, hissing ball.

53. Midsummer 1883. Late afternoon. Über Land und Meer 32, 127, 1889/90.

54. 1 February 1884. Tours. Sauter. Curriculum of the Ulm Gymnasium. 1891/92, p.21 after Ann. Soc. météor. 1884, April.

55. 24 February 1884. 7.45 p.m. Amiens. v. Urbanitzky. Die Elektrizität des Himmels und der Erde. Vienna, Pest, Leipzig 1888. Literal translation from La lumière électrique.

56. 14 May 1884. Midnight. Süder Brarup (District of Schleswig). H. Brodersen, op. cit. No. 513.

57. 28 July 1884. 1 p.m. Handewitt (District of Flensburg). H. Brodersen 505.

58. August 1884. 1 p.m. Manciano (Arrezo). Atti della Pontif. Accad. Rom. dei Nuovi Lincei 66, 59.

59. 25 June 1885. About 8 p.m. Säntis. Report: Köppen in Met. Zs. 5, 158, 1888.

60. 20 July 1885. Midday. Velletri. Mem. Pontif. Accad. Rom. dei Nuovi Lincei 29, 273, 1910/11.

Toward noon on 20 July 1885 a ball lightning was observed in Velletri, where, before the onset of rain and hail, a cylindrically shaped lightning made the rounds in two houses. At about the same time a red ball of about 15 cm diameter appeared above the two dwellings. It moved 200 m toward the east and then followed a downward sloping trajectory in the same direction. Just before the ball arrived at the end of its path, it entered an open window of the Graziosi palace and slowly approached the left cheek of a young lady standing directly in front of the window; it suddenly turned around and vanished without making a noise. The lady, who felt only a brisk hot breeze on her cheek, was terrified, and swooned; there was no shock or stinging sparks. These observations were related to me on the same day by several eyewitnesses; the threatening, but, as it turned out later, harmless jest was told to me not only by the young lady in question, but also by a woman, who had watched the whole awe-inspring spectacle from the door opening.

61. 9 October 1885. 8.25 p.m. Constantinopel. C. Flammarion. Les phénomènes de la foudre, p. 101.

Mr. Mavrocordato wrote to me from Constantinopel that while he and his family were sitting at the table in a room on the ground floor of his home they saw a fireball the size of an apple enter via an open window. The ball brushed a gas burner, then headed toward the table, circled around the lamp right above the table, and finally landed on the street, where it exploded with a dreadful crack without causing any damage or inflicting any injury. Not far from the scene of the spectacle there were numerous buildings provided with lightning rods. No odor as the result of the phenomenon could be detected.

62. 10 April 1886. 3.30—4 o'clock. Hirschberg (Silesia). Met. Zs. 3, 510, 1886.

On April 19 and 29 of this year (1886) thunderstorms broke loose over Hirschberg whereby ball lightnings were observed.

a. In the afternoon of April 19 the sky became overcast with clouds from the NNE; at 3.30 the first intense lightning flash was seen and was followed by thunder. At the same time a smaller thundercloud approached from the SE and collided with the former. Most of the lightning flashes proceeded in the horizontal direction, were remarkably extended and oc-

curred after time intervals of 5—7 minutes. The last lightning flash was observed at 5 o'clock. The heavy rain became even more intense after the
3 lightning. During the thunderstorm as well as during the whole day a strong NE wind prevailed. As far as I know, the lightning merely struck a fir tree in the forest, half an hour's walk from the city. Only two ball lightnings were seen during the storm. One was observed by the locomotive driver's wife, Mrs. Petitjean, and her son, a second-grade student at the local gymnasium. They were standing at different windows, which looked out upon the building site at the corner of the Wilhelm- and Inspektorstrasse, on the third floor of the house of the family Timm. A dazzling fireball yellow in color and the size of an average-sized skittle ball descended with a faint noise, like that produced by a flag fluttering in the wind, at relatively slow speed past the telegraph wires along the street and landed in the middle of the building site, which was overgrown with grass. Whether it touched the ground, could not be established with certainty. Immediately thereafter it lifted again and passed over the houses on the Inspektorstrasse at a greater height and with greater speed than during its descent. The young Petitjean quickly opened the window in order to follow its course; he still managed to catch sight of it near the high building of the Gymnasium, behind which it disappeared. The distance between the Wilhelmstrasse and the Gymnasium amounts to 250 m. The first 26 m of its path, i.e., until it landed, was covered in 2—3 seconds. It traveled in the direction SSW. The accounts given by mother and son are in accord with one another. The exact time could not be established.

b. The second ball lightning was seen at 4 o'clock by Mrs. Hornig, the wife of a clerk, from her home, which is located next to the gable-end of the inn "The Brown Deer" on the second floor. " The Brown Deer" is located on the Bahnhofstrasse diagonally opposite the organist's house of the Church of the Divinity. The yellow fireball flew very fast from the Franzstrasse over the houses, passed her windows at a distance of about 20—25 m in the approximate direction from S to N, flew over the Bahnhofstrasse and then vanished without leaving a trace on the steep tile roof (on which a lightning rod was mounted) of a house somewhat set back in a garden. The size of the fireball corresponded to that of a child's head. Closely behind this ball there followed a series of 4—5 smaller balls the size of billiard balls. No noise was heard. The woman immediately told her children — a grown-up daughter and a son — who were in an adjoining room about the strange phenomenon she had just seen. She is a simple, honest woman, who replied to my subsequent questions that she was sorry not to have noticed more than she had accounted for, since the balls appeared so suddenly and since she had never seen anything of the kind before.

4 **63.** 29 April 1886. 2.30—3 p.m. Hirschberg (Silesia). Met. Zs. 3, 511, 1886.

64. 14 May 1886. 5 p.m. Wigandstal (Iser Mountains). Met. Zs. 3, 512, 1886.

65. 3 June 1886. 6 p.m. Agnetendorf (Silesian Mountains). Met. Zs. 4, 171, 1887.

Chief postal clerk Klingert reports:

At about 5 o'clock in the afternoon the thunderstorm gathering from the W was starting to manifest itself by an incessant movement of the armature in the Morse apparatus. When it came closer and sparks started to appear at the lightning arrester plate, I grounded both leads. The crackling and sparking in the arrester became more frequent and intense until suddenly the room was hit by such a bolt that the windows rattled and fire made its way around all corners of the room; I was completely stupefied. I switched off the grounded apparatus in the telegraph booth and went up to my quarters which are on the first floor. At about 6 o'clock there followed a second, possibly even more powerful bolt, which caused me to jump to my feet and tear open the door, which is located at the end of a short and narrow corridor, which opens into the $3\frac{1}{2}$ m^2 large and 3 m high wood-paneled vestibule, from which stone steps lead to the ground floor and a wooden staircase to the cellar. Here I saw before my very eyes, hovering at a height of $1\frac{1}{2}$ m above the vestibule floor, a round flame reddish yellow in color, which soon thereafter vanished with a small explosion, somewhat like that produced by a blasting cap. The door of the office as well as the frontdoor were shut. An immediate check of the apparatus showed that at certain places the lead-in wires as well as the groove and the plug of the lightning arrester were fused.

66. 1 July 1886. Afternoon. Grossaupa near the Schneekoppe. Met. Zs. 4, 172, 1887.

67. 7 July 1886. Gray. L'Astronomie 1886, p. 431.

During the storm, which broke loose over the city of Gray on 7 July 1886, my friend Vannesson, president of the court of justice, observed a fireball whose diameter was apparently 30—40 cm. Accompanied by intense lightning and roaring thunder it landed on the outer edge of the ridge of a roof, whereupon it developed into a grenade and tore to shreds the outer portion of the main girder over a length of about 0.60 m like a box of matchsticks; however, no fire broke out. The store room was covered with fine splinters of wood and the plaster on the walls of the floor below was shaken loose. From here it jumped onto the roof over a small outside staircase, made a hole herein, smashed the tiles to bits and hurled them about, then fell onto the street and vanished somewhat further amidst a group of people who received no injury other than fright.

68. 14 July 1886. 10—11 p.m. Nimmersatt (Silesian Mountains). Met. Zs. 4, 170, 1887.

During a stay in the Silesian Mountains I was on my way to Ketschdorf on the evening of 14 July 1886 in the company of a young merchant from Bakenhain. The sky was covered with thunderclouds and lightning flashed in the east and west. When we arrived at the village of Nimmersatt between 10 and 11 o'clock, we suddenly saw at a distance ahead of us a luminous ball from a cloud in the northwest (from which a fairly strong wind was blowing) move along an arched path in our direction. It traveled at a height of about 1 m above the street and passed so close by me that it would have struck me had I not instinctively jumped aside. It fell behind a house, at a corner of which we stopped. I could not see the final stretch of its path, but in any case it hit the ground behind the house and exploded with a loud crack. The distance from the cloud to the ground was

covered in about 5—7 seconds. When I first noticed the ball, it seemed to be as large as a child's head; however, as it passed by me it had a diameter of ½ m and emitted a very intense light. The whole area seemed to be electrically illuminated. The ball was bright red in color and possessed a bluish fringe the width of a hand.

69. 23 July 1886. 3 a.m. Niesky (Upper Lusatia). Das Wetter 6, 68, 1889.

70. July 1886. Eickeloh. Das Wetter 13, 215, 1896.

71. 24 August 1886. Schneekoppe. Curriculum of the Hirschberg Gymnasium. 1888, p. 6.

On 24 August 1886 a thunderstorm approached from the direction of Forstlangwasser and broke loose over Krummhübel. I was standing under a colonnade in the garden of the Schneekoppe Hotel, the front of which faces the village street with the telegraph wire from the mountain peak. Suddenly I heard a peculiar explosion and saw on the right above the side colonnade a yellowish fireball about ½ m in diameter which moved along a downward sloping trajectory across the garden right past me toward the path between the colonnade and the hotel, where I lost sight of it. It happened so unexpectedly that I am at a loss to say where the ball landed; owing to its great speed I likewise could not establish whether it was perfectly spherical in shape. In the telegraph booth, which is located on the opposite side of the hotel, an explosion like the report of a rifle was heard and it was found that the lightning arrester plate was fused in certain places.

72. 24 April 1887. Mortrée (Orne). La Nature 15, 90, 1887. 2nd Sem.

73. 26 April 1887. 4.30 p.m. Liegnitz. Das Wetter 4, 137, 1887.

Soon after 3 o'clock in the afternoon a dark cloud front started to build up with increasing intensity in the southeast. The first thunder was heard by the observer at 3.36 p.m. The storm remained remote until 4 p.m. under frequent rolling of thunder. Then the wind increased in strength; at 4.10 p.m. the heart of the thunderstorm arrived at SE windstrength 6. At 4.15 p.m. it started to rain, at 4.18 p.m this turned to hail, which stopped after three minutes for a period of about three minutes, but then started again, now very dense, and lasted to 4.30 p.m. The cloud cover dropped to a remarkably low level.

The hailstones were identical in constitution, equal in size (like that of a hazelnut), round and soft with large white kernels and a fully transparent outer layer. Between 4.24 and 4.30 p.m. the strongest and nearest electrical discharges occurred. The observer, who closely followed the development of the storm approaching from the southeast, was standing at the southside window of his home which looks out upon his own as well as the even larger neighboring garden. The latter had a park-like layout with clumps of trees and lawns. When the hail was at its densest, there suddenly appeared between the branches of a clump of trees (located about 50 m from the window in question) a bright purple, pear shaped, luminous form with several small, spherically shaped forms thereabove at a height of about 4—5 m above the ground. This form seemed to be motionless but in

fact moved slightly downward. The phenomenon lasted about two seconds (at any rate long enough so that I could draw the attention of my wife, who was standing behind me near the middle of the room) and then vanished with a very loud explosion similar to that caused by a cannon.

47 About three minutes later the hail stopped. The lawns were covered with a white layer of hailstones. The place, where the fiery phenomenon had occurred, was enveloped in a whitish mist, which lifted only after a period of half an hour. At the site in question there were no visible traces of lightning. I could not ascertain whether the light phenomenon was observed by others besides my wife and myself. However, the peculiar thunderclap was heard by numerous people, with whom I discussed the course of the hailstorm. Everyone confirmed that the thunder heard during the hailstorm consisted of short cracks, and that one of the crashes — in fact the one before the last — sounded like a tremendous detonation.

74. 2 June 1887. Evening. Urspringen (Unterfranken). Das Wetter 14, 166, 1897.

75. 15 July 1887. Afternoon. Peterbaude (Riesengebirge). Curriculum of the Hirschberg Gymnasium in Silesia 1888.

76. 12 November 1887. Midnight. Cape Race (North Atlantic Ocean). C. Flammarion. Les caprices de la foudre, p. 84.

On 12 November 1887 at midnight a very bizarre ball lightning was observed in the vicinity of Cape Race. Suddenly a gigantic fireball appeared which lifted slowly from the sea surface up to a height of 16 — 17 m. The ball started to move against the wind and stayed close to the ship from which it was observed. Then it ascended in the direction southeast and disappeared. The phenomenon lasted about five minutes.

77. 3 March 1888. 7 p.m. Bischofsrode near Eisleben. Wetter 5, 94, 1888.

78. 19 May 1888. 6 p.m. Near Ottensen. Met. Zs. 6, 231, 1889.

79. 17 June 1888. 9.39 p.m. (Prague time). St. Stephan on the Gratkorn. Mittlg. Nat. Ver. Steiermark 25, 228, 1888.

80. 28 June 1888. 3 p.m. Böhnhusen. H. Brodersen. Blitzschläge in der Provinz Schleswig-Holstein, No. 987, p. 131.

48 81. 30 July 1888. 6 p.m. Vladikavkaz. La Nature 16, 415, 1888. 2nd Sem.

Prof Müller of the Emperial Russian Lyceum in Tashkent recently wrote the Geographical Society that on 29 July an extensive thunderstorm had taken place over this city and its surroundings. In the heart of the dense clouds, which darkened the sky, powerful lightning discharges occurred without interruption; the thunder rolled heavily. The phenomenon lasted

three hours without a drop of rain; however, the air was perceptibly purified and the temperature had dropped.

At 6 o'clock on July 30 — explains an eyewitness — I was walking not far from Vladikavkaz along the slope of a wooded mountain, when I suddenly heard a heavy noise; I stopped and noticed below me a group of fireballs in the form of a rosary. They moved very slowly in the direction of the valley. I could clearly distinguish three balls: the middle one was gold with yellow reflections and was two feet in diameter. On both sides of this fireball there were two beautiful purple-colored balls. The phenomenon lasted three minutes.

82. 31 August 1888. Night. Stolbergsdorf near Reichenbach. Das Wetter 5, 208, 1888.

83. 2 October 1888. 6.30 p.m. Malagny (Canton of Geneva). La Nature 17, 1st Sem. 226, 1889. Report of Dr. A. Wartmann at the meeting of the Geneva Physics Society of 20 December 1888.

84. 30 November 1888. Evening. Brest-Brescauvel. La Nature 17, 39, 1889, 1st Sem.

85. 3 June 1889. 11 p.m. Immenstadt (Schleswig-Holstein). Brodersen. op. cit. No. 1098.

86. 8 June 1889. 5.30 p.m. Cossipore (Calcutta). Nature 40, 295, 1889.

87. 13 July 1889. 3.30 p.m. Friedrichshafen. Official gazette of Württemberg No. 163, of 16 July 1889.

Friedrichshafen, 13 July 1889. On this day Their Royal Majesties quietly celebrated their 43rd wedding anniversary.

During the storm, which broke loose over Friedrichshafen in the afternoon of the same day between 3 and 4 o'clock, lightning struck the castle garden only a few feet away from His Royal Majesty the King, who was sitting under the overhanging roof before his study. It passed a high acacia, without appreciably damaging the tree itself, and struck the ground, forming two ray-shaped holes at its foot which laid the roots bare. At the same time there appeared on the lawn between the acacia and a star-shaped flowerbed a peculiar light phenomenon in the form of a large fiery ball, which was visible for several seconds, then ascended with a roar and disappeared with a crackling noise.

88. 5 August 1889. 5 p.m. East Twickenham. Nature 40, 415.

89. 23 August 1889. 8 p.m. Hermagor (South Austrian Alps) Kärnten. Mitt. Nat. Verein Steiermark 27, 423, 1890.

On 23 August 1889 a large number of thunderstorms passed over the Gail Valley. At 8 p.m., just as a powerful discharge took place, a ball lightning was observed in the hotel of Mr. P. Rieder in Hermagor. At the time in question Mrs. Rieder, her daughter and a maid were present in the kitchen

on the ground floor of the hotel, which is located at the center of the market. The maid was standing by the door with her face turned toward the stove. Suddenly a violent lightning flash followed, and at the same moment she saw a luminous ball the size of a skittle ball above the stove. It emitted a bluish light similar to that of a spirit flame. It revolved, moved over the heated stove and then dropped to the floor. Further observations could not be documented, since the above three persons fled from the kitchen. Upon entering the kitchen some time later no trace of the electrical phenomenon was found. Whether its disappearance was accompanied by a detonation remained undecided, since the thunder was raging at the same time. The account of the maid, who just happened to be looking straight at the stove during the event, seems to be reliable evidence that the fireball did not enter the kitchen from the outside but took form above the stove just as the lightning flash occurred. It should still be mentioned that even though the thunderclap at 8 p.m. was quite loud, the general impression was that the lightning had not struck in the immediate vicinity.

90. 21 September 1889. 7.30 p.m. Niesky. Das Wetter 6, 237, 1889.

91. 31 October 1889. Night. At sea. La Nature 17, 334, 1889, 1st Sem.

92. End of July 1890. At night. Harmrode near Vacha. Das Wetter 7, 192, 1890.

Recently, in the vicinity of Harmrode lightning struck farmer's Waitz's farmyard. As a result the entire surrounding building complex burned down. According to Waitz the phenomenon was a manifestation of ball lightning. On the fateful night in question he heard thunder, which increased in frequency and intensity toward the early morning; he got out of bed and went to the window. At this moment a lightning flash and a thunderclap occurred simultaneously; he jumped backward, but quickly recovered from the initial shock, looked down into the farmyard, which was surrounded on all sides by buildings, and saw a fiery mass a few paces from the woodshed. He immediately hastened to the farmyard, picked up an old bucket, which was completely dry owing to the prevailing heat, and scooped up some liquid manure in order to extinguish the firemass. However, the bucket fell to pieces before he reached his target; at this moment ray-like lightning streaks emanated from the fiery mass in all directions toward the surrounding buildings and set the entire complex on fire. Incidentally, the farmer could count himself lucky that the bucket fell to pieces. The attempt to drive the electrical fireball out of his farmyard with a bucket of liquid manure could have proven to be a fatal mistake.

93. 10 August 1890. Theux. Ciel et Terre 11, 348.

94. 17 August 1890. 7.50 p.m. Pless (Pszczyna). Das Wetter 7, 238, 1890.

In a letter from Dr. Kratzert MD to Prof. Galle in Breslau:

On Sunday, August 17 of this year I was traveling on the road from Bad Goczalkowitz to the city of Pless (Pszczyna), where I live. At approxi-

mately 7.50 in the evening, about $2\frac{1}{2}$ to 3 km from the city, I ran into a series of thunderstorms, which covered the entire horizon from the southwest via north to the east and extended upward up to the zenith, while that portion of the sky behind me was cloudless. Judging by the origin of the various lightning flashes, I distinguished between four thunderstorms: the first was remote in the direction southwest, the second linked up in the northwest with the first, extended further from the northeast to the north and was substantially closer; the third approached from the east and was apparently at the same distance as the second thunderstorm. Whereas these three storms comprised diffuse cloudmasses and the first and second represented rainstorms, the fourth thunderstorm, which was located at half elevation in the southwest sky, comprised dark, sharply outlined towering cloudmasses, which were completely isolated from the other thunderstorms by patches of clear sky. The size of this cloud formation corresponded to an area of about 0.6—1.2 acres; the shape was more or less rounded. The lightning flashes exhibited great diversity in color and direction in accordance with the different locations. Whereas in the first two storms dazzling white flashes alternated with glowing red lightning discharges and followed an almost vertical path, the lightning flashes from the storm in the east exhibited (with the exception of a few vertically downward darting flashes) a predominantly horizontal or bent downward course, whereby the initial, vertically downward directed limb suddenly sidetracked toward the horizontal and finally zigzagged along a receding course in the horizontal direction. Apart from the blue light of these flashes a remarkable feature was their intricately branched structure.

From the isolated, nearby storm, which I designated as the fourth, I observed only 3 or 4 glowing white lightning discharges strike the ground at larger time intervals. Furthermore, there prevailed a sinister silence in this cloudmass which became even more threatening the more it was illuminated by the surrounding lightning flashes. I now directed all my attention to this cloudmass and was deliberating why no lightning discharge had occurred for such a long time, when suddenly a dazzling white sphere about 20 cm in diameter appeared from the center of this mass of cloud and descended slowly and steadily vertically downward. Halfway down this sphere burst and six luminous bodies dropped like flares in slightly diverging directions toward earth and died out almost simultaneously after covering two thirds of their trajectory. It appeared to me that the falling speed of these bodies was more accelerated than that of the sphere; it also seemed as if the dazzling white light became reduced in intensity. The entire spectacle lasted ten seconds. As the sphere burst I heard no noise, but instinctively stepped aside when at the moment of the burst the telegraph wires to my side started to hiss and seethe in a way I had never heard before. During the entire stretch home — I was traveling at a walking pace — I kept my eyes fixed on the cloud, but did not see any more lightning come forth from it. In my opinion this natural phenomenon was a manifestation of ball lightning.

95. 19 August 1890. St. Claude. Comptes Rendus 111, 492—496.

Prof. Cadenat of the Collège de Saint-Claude reported the following about a tornado which struck the city on August 19:

Among the electrical phenomena, which accompanied the funnel-shaped cloud, the fireballs were most frequently and definitely identified. All the

accounts accumulated from St. Claude as well as from the villages through which the twister passed are identical in content and show no disparities whatsoever. Let us consider some of the established facts:

a) A farmer from Vizy, who was driving his cattle back to the farm and was completely taken by surprise by the tornado, saw a fireball plunge at tremendous speed. Possessed with fright he threw himself immediately to the ground. The luminous sphere smashed into the ground, exploded with a crash and covered him with dust. This was the only case in which an explosion was established.

b) Inhabitants of Vers l'Eau and Samiset saw how spheres, which were the size of a head and vivid red in color, moved slowly toward some haylofts, where they set the hay on fire and then vanished.

c) In Saint Claude many people, who at the time of the tornado had to struggle against the strong wind in order to shut their windows, witnessed fireballs the size of a billiard ball which were swept at tremendous speed in the direction of the funnel. Many others saw fireballs enter their dwellings via the chimney or furnace door and move slowly through the room, leaving behind slightly twisted streaks.

d) Mr. Mermet, Rue du Pré, observed three fireballs descend into the yard behind his house. Two carried out a hovering motion somewhat above the ground. The third was deflected by an iron rod, which the wind had torn off a wall, located slightly above a window. It then dropped to the ground and rolled a distance of several meters. Suddenly it changed its course and entered a vestibule, from which steps lead down onto the street. Upon reaching the bottom of these steps, the sphere passed between the wall and the open door, practically destroyed the lock, tore the ironwork off the door and then entered the street, whereby it left a wide hole in the door and literally split it from top to bottom. In the printing press of the Echo de la Montagne the journalist Enard saw fireballs, which, attracted by the iron points of a grate, jumped from one point to another during the tornado.

The architect Hytier, who witnessed the approach of the whirlwind from his balcony, remarked that the funnel was traversed in all directions by
3 numerous fireballs. Furthermore, a large quantity of sparks, which filled the air, was observed. Loss of human life is not attributed to this lightning (probably owing to its peculiar form) since it may be asserted that of the five persons that were killed none was struck by lightning.

I forgot to mention that Mr. Gauthier, professor in Sentier (Switzerland), informed me of three cases of ball lightning in this community.

It is of interest to consider the material damage which is ascribed to the ball lightning. There are several reports of twisted door locks; also a large number of circular holes were found in window panes on the sides of the houses exposed to the storm. Their diameter as a rule was 8 cm; the fracture was even, not star-shaped, smooth on the inner surface and exhibited a small sharp edge on the outer surface. In certain cases there was a series of concentric wave patterns around the circular hole; their amplitude was constant, while their height decreased toward the edge. Moreover, all around the onset of fusion had taken place. This effect was particularly evident at the railway station. The thickness of the glass varied over a space of about 1 cm, becoming thinner toward the edge of the fracture.

In conclusion, I shall refer to the following two facts, which pertain to events that took place in the room of the director of the gas works. The fibers of a white cotton curtain had been ruined in a most peculiar way. On first sight one would have noticed nothing; but the slightest contact transformed it into rags. Here, I lay before you a sample of this curtain. The second, a yellow damask curtain was bleached at the middle in certain spots. This was obviously due to the bleaching effect of ozone. Finally, a typical sulfur odor, which originated from the ozone produced by the lightning, spread everywhere as a result of the ball lightning.

96. 6 March 1891. 1—3.30 in the morning. At sea, 38° lat. N 41° long. W. Ann. d. Hydr. 20, 257.

97. 2 January 1890. 9.15 p.m. Pontevedra (Spain). La Nature 18, 167.

98. 1 July 1891. 11.30 p.m. Potsdam. Das Wetter 8, 165, 1891.

Motivated by an article in the paper, whereby mention is made of the repeated observation of ball lightnings during the heavy thunderstorm on the night of July 1 to 2, I would like to inform the Royal Meteorological Institute that I also observed a similar phenomenon from my house at No. 3 Brauhausberg. Although I can report only little about this event, the exceptionally long duration of the phenomenon (at least three minutes) should nevertheless be of interest.

At 11.30 at night, about 15 minutes before the thunderstorm reached the peak of its development, I suddenly noticed at 8° elevation above the horizon in the direction WNW a star having the brightness of Sirius, white in color with a tint of red and which slowly moved along a horizontal path. Since the star passed about 5° above the roof edge of the brewery on Wastermann Heights, the path it followed could be established with certainty. After two minutes of unattenuated luminosity the star began to fade and vanished completely one minute later. The total path covered by the star within three minutes was about 8°.

In conclusion, I would further like to point out that at the indicated elevation above the horizon the star could not have been mistaken for some light source on earth.

Prof. Dr. Albrecht in Potsdam.

99. 1 July 1891. 3—4 a.m. Berga near Sohlichen. Das Wetter 8, 165, 1891.

During the very heavy thunderstorm, which passed over the region in question between 3 and 4 o'clock in the early morning of July 1, a lightning discharge struck the small house of a carpenter in Berga, about 1 km from here. The lightning entered the chimney, shattering the latter, and split into two streaks on the roof. The less intense streak crept along the rafters, while the more intense streak entered the furnace via the furnace pipe, tearing off the upper layer of the former; it then made its way toward a bedstead, which was likewise smashed to splinters, and finally, after putting a hole through the mud wall, penetrated into the ground at the adjacent wall. The carpenter, who shared the single small room of the small house with his wife and three children, related the following course of events to me:

He was sleeping with one of the children in the bed which was subsequently smashed, while his wife and second child were sleeping in the adjacent bed, in front of which stood the cradle with the youngest child. As the thunderstorm broke loose the carpenter got dressed and the child who was sleeping with him sat up on the edge of the bed. His wife remained in bed. Suddenly, with a heavy rumbling noise a round fireball jumped from the furnace onto a bed, as a result of which the latter collapsed; then the fireball rolled toward the cradle and his wife's bed at such a slow speed that the carpenter, possessed with fear for his beloved ones, managed to get to the cradle just in time. Thereupon, the ball vanished through the
55 wall or floor with a fearful crack. Miraculously, none of the five persons was injured or even bewildered. All complained of headache because of the dense sulfur mist, but soon thereafter recovered again. The carpenter's wife, who was lying in bed, had only noticed a glare of fire. Since the small house was completely surrounded by trees, the neighbors unfortunately could not observe the form of the lightning. However, on the basis of the unpretentious account of the carpenter we can assume that this was a case of ball lightning.

100. 1 July 1891. 10 p.m. Sanne-Kerkuhn. Das Wetter 8, 166, 1891.

On July 1, an exceedingly stormy day, there appeared at 10 o'clock in the evening during the fifth thunderstorm of this day in the direction southeast about 40° above the horizon a type of luminous ball the size of a full moon, emitting an intense white light, which after about 10 seconds disappeared again in the thunderclouds, just like a full moon hides behind clouds.

101. 31 July 1891. Afternoon. Chemnitz. Das Wetter 8, 214, 1891.

During a thunderstorm on Friday afternoon, July 31, an interesting phenomenon was observed in Chemnitz. A so-called ball lightning landed in the vicinity of the Burgkeller inn. Right in the middle of the Annabergerstrasse there suddenly appeared at house height a fireball the size of a skittle ball; this ball quickly contracted and exploded like a bomb with a powerful crash. Streaks of light shot out in all directions. The main streak found its way to a building on an estate and damaged the gable and chimney top.

102. 11 August 1891. Brücke. Mittlg. Nat. Verein Steiermark **28**, 348, 1891.

103. 18 August 1891. 2 p.m. Martinique. Comptes Rendus **113**, 421, 1891.

The electrical discharges followed one another incessantly; lightning flashed continuously; it increased and decreased in intensity and number before and after the passage of the storm center; the intensity of the thunder was very difficult to assess, which was probably due to the fearful noise caused by the wind and falling roofs and houses. Ball lightnings were seen everywhere during the hurricane. Country people talked of fireballs, which flew through the air for several minutes while making a crackling noise and burst at about 50 cm above ground.

104. 11 December 1891. 5 p.m. Veröff. Königl. Preuss. Met. Inst. Berlin. 1895, p. XXIV

105. 12 December 1891. 2.30 a.m. Wilhelmshafen. Ergebnisse der Gewitter. Beob. 1891. Veröff. Königl. Preuss. Met. Inst. Berlin 1895. p. XXIV.

106. 7 August 1892. 9.00 a.m. Altenmarkt near Fürstenfeld. Met. Zs. 9, 355, 1892.

107. 10 August 1892. Miesenbach. Mittlg. Nat. Verein Steiermark 29, 427, 1892.

On August 10 during a thunderstorm a reddish fireball the size of a head was seen moving over a meadow in Miesenbach. Schoolchildren observed this ball at a distance of only 6 m. It traveled at a steady speed, reached the ground and vanished without any noise, after it had been visible for about one minute. It was stressed that the fireball did not come from a cloud.

108. 1 November 1892. Afternoon. Atti della Pontif. Accad. Rom. dei Nuovi Lincei 1892, Ser. 5, Vol. 1(2), p. 308; (Naturwiss. Rdschau. 8, 62).

109. September 1893. 7 p.m. Casarano Mem. della Pontif. Accad. Rom. dei Nuovi Lincei 28, Ch. 30, 1909.

On a September evening of the year 1893 Professor Giuntini and three of his friends were sitting around a table playing cards on the ground floor of a country house near Casarano in the province of Lecce. Toward seven o'clock a storm with pouring rain and hail passed over. Suddenly a large oblong sphere having the shape of an amphora descended from the roof; it was 25 or 30 cm high, green, very lustrous, and was streaked in red and yellow at the upper end. It circled two or three times around the group of four friends, whereby it contracted to an almost spherical form, and then flew out via an open window. Only Professor Giuntini felt a slight pain in the right shoulder which lasted for half an hour.

110. 1 August 1895. 3.30 in the afternoon. Hirschberg (Silesia). Met. Zs. 13, 25, 1896.

Zabel, a boy of about 15, related the following to the reporter: On August 1 of this year at 3.30 in the afternoon I heard thunder in the distance and since it started to rain, was about to shut the window of our ground-floor flat on the Stonsdorferstrasse. Suddenly, at the corner of our street and the Wilhelmstrasse I noticed a reddish yellow ball about $\frac{1}{2}$ m in diameter which hovered at the height of the first floor and which continually emitted rays downward during the 10—15 seconds that it was visible. I could only see the upper portion of this ball, since bushes partly blocked my view. The ball moved very slowly several feet to the right while revolving about a horizontal axis. It was vanished with a deafening detonation, which was accompanied by a clattering noise, as if numerous windowpanes were being smashed. The moment the ball burst a lightning streak shot out toward the house of Colonel Hardt on the left corner. After the storm I

immediately went to the spot where the ball had exploded, but could not find a trace of it. The window, at which I was standing, is about 60 paces away from the Wilhelmstrasse.

The detonation must have been very loud, since all the inhabitants of the surrounding houses thought that the lightning had struck their own dwelling. The bandmaster Voigt, who at the time in question was standing among the trees in his garden on the Stonsdorferstrasse, told me that he had never heard such a violent thunderclap or anything similar to it; deeply frightened, he dashed into the house to check the welfare of his family. Further, a sulfur odor had spread over the entire area.

111. 24 August 1895. 10 a.m. Calvières. C. Flammarion. Les caprices de la foudre, p. 83.

On 24 August 1895 toward 10 o'clock in the morning during a thunderstorm with rain several persons saw a white ball descend from the sky; it had a diameter of about 2 cm and, after landing on the ground, it split into two smaller balls. These two balls lifted again into the air up to the height of two adjoining chimneys from two neighboring houses and then vanished. One of the two balls went down a chimney; it traversed a large room, in which there were a man and a child, without inflicting any bodily harm upon them, and then penetrated before their eyes into the floor, whereby it pierced a stone like a punch. The only trace left by the lightning was an opening barely the size of a franc. Below the
58 above-mentioned room there is a sheepfold. The owner's son, who was sitting on the threshold, suddenly saw a shining light above the flock, while the sheep were jumping around madly. When he got up to calm down the sheep and approached the site, he discovered with surprise that five sheep had just been killed by the heavenly fire. The animals showed neither signs of injury nor traces of burns; only on their lips there was some reddish foam. In the house next door a fireball had come down the chimney and exploded in the kitchen, causing a great deal of damage.

112. 7 September 1895. 9 o'clock in the evening. Hirschberg (Silesia). Met. Zs. 13, 25, 1896.

113. 2 October 1895. 8 p.m. Grenoble. Comptes Rendus 121, 596.

After a drought of several months in Grenoble the rain finally started to fall on Wednesday afternoon, October 2, 1895. Even though there was no lightning or thunder, the weather was still oppressive and sultry. The rain fell under the same conditions during the whole day. At about 8 o'clock, when I walked up to a window, I suddenly saw a large fireball appear on the point of an iron rod, which was mounted on the roof of a neighboring house in order to support telegraph wires. Since the distance between me and the house in question was only 100 m, I could observe the phenomenon very clearly. This ball, whose contour, despite the luminous emission, seemed to be sharply outlined, may have been 30 cm in diameter. It has the lustre and appearance of a powerful electrical furnace. From the point of the iron rod there emanated a continuous stream of fairly large sparks, which seemed to originate from the white-hot iron platelet. These sparks were remarkably similar to those produced by a blow of a piledriver. The stream of sparks was directed downward.

[redacted]

After a while, which I estimate to be about 40 or 50 seconds, the fireball suddenly split into three smaller balls, each the size of a children's balloon like that sold on the street. The sparks stopped immediately and the three balls, which were identical in appearance to the first fireball, seemed to roll down the roof as if merely under the influence of gravity. Upon arriving at the gutter (or perhaps upon touching it, since at this instant several sparks appeared again) all three balls disappeared without producing a detonation.

Almost immediately thereafter a second fireball appeared on the point of the same rod. However, it vanished after 2 or 3 seconds without a sound. At the same time a stream of sparks emanated from the point of the rod and was similar in size and color to the previous one. This stream followed the same direction as the first one.

59 I consider it relevant to add that at about 5.30 a trustworthy person had seen two fireballs at the same place and with the same time interval of several minutes, and had exchanged a few words with me about this.

The next morning I noticed that the iron rod was no longer upright, but exhibited a very conspicuous kink.

I subsequently discovered that on the same evening several persons had observed similar phenomena at different places in the city.

114. 1895. Karachi (Sindh). Le Cosmos 46, 95, 1897.

G. M. Ryan reports the following personal observation of a ball lightning in Karachi: he was sitting in his room with two friends, who had sought shelter from the thunderstorm. He got up to open the door (all the doors and windows had been shut). As he came back he saw a fireball the size of a full moon hovering in the air above his two friends. At the same instant a loud thunderclap was heard. The two were slightly injured; one suffered from a sharp pain on the left side of the face, while the other had experienced a shock in one of his arms and at the same time had the impression that his hair was on fire. A pungent sulfur odor started to develop. In an adjoining room there were two carbines in a rack. One of these had not been touched; the other, however, had been struck, since a hole was found at the point where the muzzle leaned against the wall; on the upper floor the same wall exhibited two holes.

115. 5 June 1896. 11 p.m. Paderborn. Das Wetter 13, 185—192, 1896.

116. 5 June 1896. 4 p.m. Ahrenviölfeld (Schleswig-Holstein). H. Brodersen, loc. cit., 1899, p. 95 and 178.

117. 18 June 1896. 2.15 p.m. Hjelsäter. Westgothland (Sweden). Met. Zs. 13, 475, 1896.

Engineer Count Gustav Hamilton writes the following about a lightning which struck the Hjelmsäter estate on the Kinnekulle, a mountain on the east bank of Weener Lake in Westgothland.

At 12.30 p.m. the thunderstorm started, but its activity increased toward 1 o'clock to such an extent that the telephone apparatus was put out of order. At 2 p.m. the storm seemed to have reached its peak activity; at 2.15 p.m., however, the following took place: my parents, two brothers,

my fiancée and myself were sitting at the table in the dining room. I had just counted 20 seconds between a lightning flash and the thunder and thought that the storm was starting to move away, when all of a sudden we saw a white luminous ball hovering above the table and shouted in unison: "Look!" At the same moment the ball exploded with a loud detonation and an intense emission of light which flung us violently against the backs of our chairs. Nobody was hurt; only my hair and clothes were somewhat singed, so that there was the smell of something burnt. With the exception of a few small pieces of cheese which were blown off the plate, the tableware was likewise not damaged. A door leading to a covered veranda and a window were open. For a while we felt as if we were lamed; each of us had observed the phenomenon in exactly the same way. The maidservant, who was busy in the adjoining pantry, fell forward to the floor but did not see any light. The kitchen is located below in the middle of the ground floor. The cook was alone there. She saw "flames all about and felt herself being lifted up into the air." No material damage whatsoever was found in the entire house. Three numbers had fallen off the electrical bell. The house was not provided with a lightning rod. Right after the explosion of the fireball an ordinary lightning discharge occurred which split two trees outside the house.

118. June 1896. Sainghin. Le Cosmos 45, 387, 1896. N.S. 34.

119. 10 July 1896. 7.30 p.m. Carlskrona (Sweden). Met. Zs. 13, 476, 1896.

Naval Captain J.A. Baron of Duben writes: A heavy thunderstorm started at about 7.30 p.m. on July 10. I was sitting with four friends in a room between the anteroom and another room. In both rooms windows on adjacent sides were open. Soon thereafter a small fireball (ball lightning?) entered via the open door of the anteroom and approached us; it moved about one meter into the room and then suddenly exploded with a bang; the detonation was comparable to the report produced by a Russian cracker — a children's toy consisting of a paper ball with explosive mixture which makes a bang like a blasting cap when thrown against the floor. Among those present in the room, four clearly saw the phenomenon. The bang was heard by more than ten people who were in the vicinity. My residence is on the ground floor of a small, one-story house on the seaside and has no lightning rod. None of us noticed any physical effect.

120. July (first half) 1896. Afternoon. Hirschberg (Silesia). Das Wetter 14, 167, 1897.

Miss Anna Peters, governess at the home of Lieutenant von Branchitsch in Hirschberg, sent me after a preliminary oral account the following note: "On an afternoon in the first half of July of last year I was sitting during a fairly heavy thunderstorm somewhat to the side of and about 2 m from an open window, in a room on the second floor of the von Branchitsch villa. Suddenly a pink ball about 20 cm in diameter floated via the window into the room. It revolved and slowly approached me. Since I had the feeling the ball was going to roll into my lap after it had approached to within my direct vicinity, I jumped up frightened; at the same moment I heard a thunderclap and the ball had vanished. The entire event lasted about five seconds."

I might add that Miss Peters told me how the ball revolved about a horizontal axis, which was transverse to the direction of motion of the ball, in such a manner that the rotation on the side facing her was from the top downward. Miss Peters must have therefore observed the phenomenon very clearly.

Dr. E. Reimann.

121. August 1896. 2.30 p.m. Frascati. Atti. della Pontif. Accad. Rom. dei Nuovi Lincei 66, 62.

122. 1896. Remscheid. Prometheus. 18, 576.

An exceptionally heavy downpour in the year 1896 in Remscheid caused me to look out through a window, whereupon I noticed a bright light and immediately thereafter at a height of about 6 m in front of the adjacent workshop a luminous ball of 50—60 cm diameter. It descended slowly, like a downward gliding bird, apparently along the slant of the rain and disappeared at a height of about 4 m with a very loud bang, but in such a way that I did not notice any fragments. The color was bright, but not blinding, somewhat like the reddish glow of a full moon. I was under the impression that the ball had developed before my eyes from the luminous rain.

123. 22 May 1897. 5.45 in the afternoon. Hamburg. Ann. d. Hydr. 25, 257.

124. 25 May 1897. 2.45 p.m. Bad Szliaes (Hungary). Das Wetter 14, 167, 1897.

In Thursday afternoon (May 25) a heavy thunderstorm broke loose over Szliaes. At 2.45 p.m. a ball lightning the size of a man's head was observed. The rare natural phenomenon was seen coming from the park (southwest); it floated above the ground at a height corresponding to that of a man and whizzed closely past the banister in front of the "Villa Buda." The upholsterer, who was standing here, was flung with his head against the stairpost. Via an open window the ball flew into a corner-room on the ground floor and passed about one pace in front of the bath superintendent, who was sitting at a table, and two paces in front of the doorkeeper, who was standing in the room; it then passed through the closed window out into the open again, whereby it smashed a hole the size of a fist through the window pane. Having reached the open air, the ball lightning struck a very high and sturdy white poplar, which stood about 15 paces in front of the building. Here, it ripped a 2-cm deep vertical gash into the bark and wood over a width of 20 cm at a height of 10 m. Leaving a narrow groove on the side of the tree, it finally drove into the ground. The detonation, which accompanied the lightning, was no louder than the report of a rifle. Nobody was injured. The fright was, of course, greater than that ever previously experienced.

125. May? 5.30 p.m. Nieheim. Das Wetter 14, 144, 1897.

126. 6 June 1897. 7.30 in the evening. Altkemnitz (Silesia). Das Wetter 14, 263, 1897.

On the first day of Easter, June 6 of this year, lightning struck the dwelling of the brickmaker Scholz in Altkemnitz; as a result the house burnt to the ground. Scholz and his family were on their way home and had come to within 100 paces from their house, when they suddenly saw how a zigzag lightning struck the roof ridge somewnat to the left of the centrally located chimney and then flashed toward the left in winding fashion along the ridge. Then "a bloodred sphere, the size of two balled fists, rolled all the way down the high, steep thatched roof to the ground." When it reached the ground, the roof started to smolder along the path followed by the ball; immediately thereafter the whole house, the left side of which served as a stable, stood in flames. Nobody saw what happened to the ball after it hit the ground; furthermore, no explosion of any kind was heard.

127. End of June 1897? Amiens. Le Cosmos, Revue des sciences et de leurs applications 46, 95, 1897, N.S. 37.

During a thunderstorm which raged in the region of Amiens toward the end of June we and our relatives saw a luminous mass, which apparently lay on the grass in a meadow about 100 m from the window from which we had a view of the surrounding terrain. It seemed to be as large as the moon — so the children exclaimed. In fact, it was difficult to say whether the mass was spherical in shape or not. The mass had such a lustre that the radiation it emitted made it possible for us to distinguish a clearly defined contour. At first, some of us voiced the opinion that one of the lightning flashes, which followed one another without interruption, had ignited the grass in the meadow. However, the lustre of this luminous mass contradicted this assumption. Moreover, the rain was coming down in streams and the meadow lay completely under water. All these deliberations were, of course, put forward after the event, since the phenomenon occurred so fast (5—6 seconds) that we hardly had the time for an on the spot assessment. A frightful detonation followed, but we could not tell whether the explosion of the luminous mass was associated with this noise; it merely disappeared — that is all that could be said with certainty. Painstaking investigations at the site in question did not disclose any trace of the phenomenon, for which reason we did not relate this event at first. Only after we heard of the observations of Wartmann and Cunisset-Carnot did we decide to publicize our own observation.

128. June 1897. Chandes on the Loire. C. Flammarion. Les caprices de la foudre, p. 85.

In the month of June, 1897, the small village of Chandes, situated at the mouth of the Vienne and Loire rivers, was visited by a ball lightning. Three persons, who were standing on a veranda, clearly saw the moment lightning struck their house how a fireball passed about 30 m in front of them and exploded with a bang, whereby sparks were hurled against the lock on the veranda door. At the same moment, the servants noticed how another luminous ball traversed a garden on the other side of the house and plunged into a water tank. A gardener was knocked to the ground, but did not suffer any bodily harm.

129. 4 July 1897. 12.50 p.m. Turnau. Mittlg. Nat. Verein Steiermark 34, 175, 1897.

Postmaster Pichler beheld a fiery ball in the post office; it was about 5 cm in diameter; from two sides emanated two identical firebundels approximately 50 cm in length. The phenomenon was accompanied by a sound comparable in intensity to the report of a pistol. The lightning struck the post office; lightning and thunder occurred simultaneously.

130. 23 August 1898. 7 p.m. Quickborn (Schleswig-Holstein). H. Brodersen loc.cit. No. 2029.

131. 22 July 1897. Lobning near St. Stephan (Leoben) on the northern slope of the Small Alps. 6,30 p.m. Mittlg. Steierm. 34, 176, 1897.

132. 6 August 1897. 2,30 p.m Wilhelmshafen. Das Wetter 14, 215, 1897.

On the afternoon of August 6, 1897, a violent thunderstorm, which came from the southwest, broke loose over Wilhelmshafen. According to the newspaper reports, at 2,30 p.m. lightning struck the steel tower for the telephone wires on top of the post office building, the naval hospital and the officers' club. A ball lightning was observed in Mr. Hasse's town pharmacy, which is located right next door to the post office. The phenomenon was observed by the two pharmacists, Gustav Stein and Willi Müller, who both happened to be in the shop at the time. I put before these gentlemen Sauter's list of questions which appeared in Met. Zs. 1895, p. 260, and obtained the following answers:

1. Exact time of occurrence, Speed of the ball lightning. It was on August 6, 1897, at 2,30 in the afternoon. Duration of the phenomenon about 3 seconds.

2. Description of the locality. The lightning entered via the open office window, which faces the courtyard, appeared on the gas bracket and left six meters through the open door onto the gas bracket in the pharmacy. There were no water outlets or sinks in the vicinity.

3. Path followed by the ball lightning. The ball lightning described an inclined path as it entered through the window. It followed a completely horizontal trajectory from the first gas bracket to the second and seemed to drop from the window opening to the floor of the office and from here jumped up to the gas bracket on the wall 6 feet above the floor. It left no trace and caused no damage. It definitely exhibited an affinity for metals, since it jumped from the metal gas bracket in the office to the metal gas bracket in the pharmacy.

4. Appearance of the ball lightning. The ball lightning was round in form, about the size of a lampshade, and was bluish in color. In the office it was surrounded by a mist envelope, but no longer in the pharmacy. Neither smell nor heat was perceived. The noise in the pharmacy was similar to that produced by the rupture of the glass chimney of a kerosene lamp; with this the phenomenon terminated and vanished. The ball lightning appeared with a violent thunderclap.

5. Observers, etc. The phenomenon was observed by the two above-named gentlemen. They had never experienced anything of the sort before. The possibility of an optical illusion due to the lightning is out of the question.

133. 3 September 1897. Evening. Hirschberg (Silesia). Das Wetter 14, 263, 1897.

134. 1897. Ligny (Eure-et-Loir). C. Flammarion. Les caprices de la foudre, p. 24.

135. October 1898. Marseille. C. Flammarion. Les caprices de la foudre, p. 19.

136. 26 June 1899. 3.40 p.m. St. Pierre. C. Flammarion. Les phénomènes de la foudre 124. Paris.

On June 26 I found myself at 3,40 p.m. in the building of the French Telegraph Company, where I was trying to put a call through to the central telephone exchange; I was requested to hang on for a moment. No sooner had I hung up the receiver than I heard a piercing noise, which originated in the lightning arrester of the telegraph apparatus. Since this is a frequently occurring phenomenon during the stormy season, I set about to connect my telephone to the ground lead, when I noticed a fireball apparently 20 cm in diameter which had the brightness of a 20-candle-power lamp bulb. It moved along the telephone wire toward the telephone. When the ball reached the receiver, a frightening discharge occurred between the latter and the ground lead, which, fortunately, was located behind the telephone and close to the receiver. This discharge was accompanied by a blinding light and produced an explosion, which, in terms of its strength, was comparable to the detonation of a low-caliber cannon. I experienced a very strong shock and was momentarily dazed. When I had regained my facilities, I connected my line to the ground and discovered that the telephone apparatus was completely burnt out. The relay of the Morse recorder was slightly damaged. The voltage in the conductor must have been enormously high; this was borne out by the fact that a long section of the coil wire had been melted. The plates of the Siemens lightning arrester of the telegraph line were melted at several places; at one of these the melted parts were welded together, so that the plates were firmly attached to one another.

137. 6 September 1899. 8.45 p.m. Leipnitz, Steiermark. Mittlg. Nat. Ver. Steiermark 36, 228, 1899.

At 8.45 p.m. on September 6 lightning simultaneously struck two houses standing opposite each other in Leipnitz and separated by a distance of 50 paces. In the northern of the two houses a woman was sitting near the open window at the time of the discharge. She saw a "fire" enter her window, while simultaneously a frightful crash shook the whole house. More than half the tiles on the roof were torn off and all the ceilings showed cracks. More details about the fire, which had entered via the window, could not be obtained from the woman, since she had been temporarily stupefied. In the other house a family was having supper around a large table, above which a large hanging lamp was suspended. Suddenly, a pear-shaped bluish yellow firemass rapidly descended along the lamp to the table, where it knocked over and smashed a glass filled with beer, while the lamp remained undamaged. Among the five people that were present three felt a shock in their limbs which caused temporary paralysis, while the remaining two persons suffered no bodily harm at all. The fiery body moved from the table toward

the side in the direction of the furnace (the glass had been thrown to the opposite side) and ended up by exploding with a loud bang. Not a sound was heard while the fireball was moving. Since the ceiling was not damaged, it would seem that this ball lightning originated and died out in the room. While this lightning was spreading fear in the dining room, another lightning struck the adjoining kitchen. No fire was caused in either of the two houses.

138. 19 August 1900. Maintenay. C. Flammarion. Les caprices de la foudre, p. 95.

139. 24 August 1900. 8.55 p.m. Berlin. Met. Zs. 18, 39, 1901.

At 6 p.m. on August 24 of last year (1900), one of the hottest and sultriest days of last summer, the sky over Berlin became overcast with a thin cover of stratus cloud. At 8 p.m. an initially weak, but soon very lively summer lightning developed in the southwest; the lightning flashes lit up the entire southern half of the sky. At 8.55 p.m. (local time), just after I had started to pay more attention to the lightning flashes, I witnessed a most peculiar phenomenon from the balcony of my home in the Bachstrasse near the northwest extremity of the zoo which provides a free view toward the south and east. Violet-colored zigzag flashes were being emitted horizontally in all directions from a small, luminous red, rounded off mass in the southern sky at an angular elevation of about 45°. On a streak directed toward the southeast there suddenly developed a reddish ball, which shone quite brightly through the lower cloud layer; I estimated its diameter between $1\frac{1}{2}$ and 2 times that of a full moon. It moved with extraordinary speed toward the southeast over a distance equal to 3—4 times its diameter and then disappeared without a sound in the same way, but only faster, as an incandescent light dims inside a frosted bell jar. The entire phenomenon lasted one or at the most two seconds. Within the next three quarters of an hour I observed more similar, pretty violet lightning streaks, which in each case seemed to emanate from the same luminous red mass in the southern sky; however, there were no subsequent moving, sharply outlined spheres, such as the one which occurred at 8.55 p.m. At 9.07 p.m. I heard faint, but definite thunder; apart from this, the lightning discharges took place, despite their closeness, without thunder as well as without rain, which according to the calculations of Meinardus was probably associated with a rapid drop in the temperature gradient and increase in wind velocity. After 9.45 p.m. parts of the sky cleared and the lightning flashes became somewhat fainter; however, soon after 10 p.m. the flashes again increased in number and intensity, while fractonimbus cloud was rapidly forming in the south. The wind, which previously blew from NE or ENE and had not exceeded windstrength 2 on the Beaufort scale, turned at 10 p.m. toward NW and increased to 3 and later to windstrength 4. After 10.50 p.m. particularly bright zigzag and sheet lightnings lit up new clouds on the southeast horizon; these clouds approached rapidly and finally formed a moderately heavy thunderstorm with more frequent thunder and a rain-shower which lasted a quarter of an hour, yielding 1.2 mm of precipitation.

The day after, when I discussed this matter with several acquaintances, I discovered that most of them had noticed the particular brightness of the flashes during the summer lightning, but no one had perceived anything out

of the ordinary. Only Dr. Nathanson, an official of the Versuchsanstalt
68 Deutscher Müller (Research Institute of the German Millers' Association), had observed several ball-like forms of lightning between 9.15 and 9.30 p.m. from a balcony in downtown Berlin. One of these lightnings, a he told me the day after, had reminded him of an experience from his youth, whereby he had once seen a ball lightning in the streets of a small town; it was similar in size to a skittle ball and rolled down the street, finally exploding with a frightful noise. He therefore had the impression that also in the case at hand the lightning which appeared in the form of a round body should have moved in some way, which, however, it did not.

After this I considered it as highly probable that not only the culmination of the lightning streak of 8.55 p.m. was a manifestation of ball lightning, but also that the luminous inner mass observed along with the above-mentioned streak as well as with the remarkable lightning discharges seen from two different sites in the city belong to the class of ball lightning and are most likely associated with one of the developmental stages.

The following numerical figures should bear some evidence as to the approximate size and speed of the ball which passed over the stratus clouds at 8.55 p.m. According to recordings taken at the agricultural college in North Berlin the air temperature at 9,00 p.m. was 26.4° C at 58% relative humidity and 750.9 mm Hg air pressure. Assuming that at this time the vertical temperature gradient corresponded to the adiabatic changes of state, we then obtain from the Hertz Table 1060 m as that height at which, upon further cooling, condensation of the water vapor should have occurred. Thus, if this was the height of the stratus clouds, and if the luminous ball observed at an angular elevation of 45° was located immediately above this cloud cover, then its distance from the observation site was about 1,500 m and its actual diameter 20.3 m, when its apparent diameter is taken $1\frac{1}{2}$ times that of a full moon, or 27.0 m, when the apparent diameter is taken as twice the moon diameter. Accordingly, we can take 20 m as the lower limit for the diameter of the ball and, since it traversed a distance 3 —4 times as large in no more than two seconds, we can regard 30 m/sec as the lower limit for its propagation velocity. Consequently, this phenomenon appreciably exceeds both in size and speed those ball lightnings which are usually observed in the direct vicinity of the ground.

140. 16 October 1900. Night. Colberg, O.-A. Nürtingen. Das Wetter 18, 24, 1901.

During the heavy thunderstorm, which recently broke loose at night with powerful lightning discharges and cloudburst rainshowers, some
69 inhabitants, who were busy sheltering harvesting equipment and other objects against the onrushing water, witnessed a rare phenomenon, namely a ball lightning. A powerful lightning ball of considerable size was seen turning about in the street after lightning had struck next to the church, rolled down a side alley with a loud crackling noise and then disappeared underneath the houses, leaving a strong sulfur odor. The eyewitnesses were almost numb with horror, but no damage was caused.

141. 1900. Wolfratshausen. A. Lippmann. Einführung in die Aeronautik I, p. 160, Leipzig 1911.

The author observed a ball lightning during a very heavy, dry thunderstorm in 1900 in the region of Wolfratshausen. A luminous, red ball seemed to

move slowly over a hill at the foot of the mountain massif and suddenly burst into several luminous points, which seemed to be connected by rays and from the center of which a powerful streak led to the ground. Immediately after there followed an extraordinarily loud thunderclap. The phenomenon may have lasted more than one second.

142. 21 April 1901. Lanxade near Bergerac. C. Flammarion. Les caprices de la foudre, p.84.

143. 22 May 1901. 5 p.m. Uralsk (Russia). C. Flammarion. Les caprices de la foudre, p. 78, Paris.

On May 22, 1901, a terrible thunderstorm broke loose over Uralsk. It was a holiday, all the streets were crowded with people. At about 5 o'clock in the afternoon several men and girls, 21 people all told, took shelter in a vestibule. A 17-year-old girl, Miss K., was standing on the threshold with her back turned to the street. Suddenly a violent thunderclap was heard and a blinding fireball appeared in front of the door; it slowly descended toward the ground and made its way to the door. After the ball had touched Miss K., who immediately bent over, on the head, it dropped to the floor in the midst of the assembled company, made the rounds, entered the door leading to the room of the caretaker, whose feet it burned, and caused all kinds of damage here: it destroyed the wall, entered the fireplace in the adjoining room, broke the chimney, struck the canvas-like iron grid and tore it with such force that it was hurled against the adjacent wall; it then left, after breaking the window panes, via the window. After the first shock had passed, the following assessments were made: the door, which was next to Miss K., had been thrown into the yard, and two holes, each 18 cm in diameter, were found in the door tapestry. The young girl, who was sitting on the threshold with her head down, seemed to have fallen asleep. Some people went into the yard, but there was nothing to see nor any sound. The others were lying unconscious on the vestibule floor. Miss K., was dead; the lightning had struck her in the neck, passed down her back and over the left hip, leaving a black trail. On a finger there was a small wound with a little blood. One of her shoes had been ripped over its entire length and in one of the stockings a small hole was found. All those struck by the fireball were unconscious.

144. 1 June 1901. 19 hr 30 min. Löwen. Ciel et Terre 22, 302, 1901.

145. 9 June 1901. 1.30 p.m. Fixin (Côte d'Or). Comptes Rendus 132, 1537.

146. 18 June 1901. 1.30 p.m. Prekopa (Steiermark). Met. Zs. 20, 316, 1903.

On June 18, according to a report by Father Slatinšek from Station Franz, a ball lightning was observed in the neighboring village of Prekopa at 1.30 p.m. during a violent thunderstorm. It was the size of a hat, reddish violet in color and moved with a hissing noise through the air at low level. It then struck the top of a great oak tree in the middle of the village and tore it to shreds down to the roots. Several people were knocked to

the ground in the process, but none were killed. The above account was given by eyewitnesses.

147. 23 July 1901. Lind near Karnburg (Kaernten). Met. Zs. 20, 316, 1903.

148. July 1902. Montmartre. C. Flammarion. Les caprices de la foudre, p. 84.

149. September 1902. Altenburg. Das Wetter 19, 239.

During the first thunderstorm of the season in Altenburg a ball lightning was seen. Initially, it seemed to be stationary or was moving along the line of sight of the observers, so that they assumed that it was stationary. Then large, star-like sparks, followed by a zigzag lightning streak, darted out of the fireball. At this moment a volley of electrical fire blinded the observers, and a deafening thunderclap was heard immediately thereafter. The lightning landed in a water reservoir in the middle of the city (despite
71 the fact that this reservoir was surrounded by high trees and houses) and killed all the fish. A second lightning also spared the surrounding high objects and struck a fence, smashing the posts to splinters.

150. 1902. Janssen Observatory, Montblanc. Le Cosmos 60, C.L. 65, 692, 1911.

151. End of May. 4 p.m. Saint-Saturnin (Vaucluse). C. Flammarion. Les phénomènes de la foudre, p. 104.

We are building a flour factory; our home is located about 180 m from the factory. The two buildings are illuminated by electricity and 16-candle power incandescent gas lamps. Toward the end of May at about 4 p.m we heard at a distance of 4—5 km rolling thunder from a storm accompanied by hail. A few drops of rain started to fall. Our stables and house are built under a common roof; a stablehand looks after the horses. During the storm this man entered the vestibule in order to fetch some oats. Instead of directly going down the steps to the store room, he waited for one to two minutes. Suddenly the cook, who was in the back of the kitchen peeling potatoes, whereby she was bending her head down, heard a faint noise in the vestibule, where the stablehand was standing; she lifted her head up and saw a mysterious light similar to an incandescent gas lamp, but with a cherry red light instead of the usual white-red luminescence; this light approached her slowly at a height of about 1 meter above the floor. This lasted about two seconds, after which she neither heard nor saw anything. The woman, who believed the stablehand was playing some kind of trick on her, went up to him and claimed that he had jokingly tried to scare the wits out of her. The stablehand had no idea what was going on. Sure enough, he had heard the hissing noise, but did not see any lamp or light. It seemed to him that the sound was moving away and up the steps. However, while the two were still arguing, a dazzling lightning suddenly flashed and simultaneously a thunderclap like a cannonade was heard. On the basis of these facts I thought that lamps or electrical wires must have burnt out; however, when at 8 o'clock in the evening the lights were turned on everything seemed to be in order.

152. 29 June 1903. 8 o'clock in the evening. Met. Zs. 20, 188, 1903.

153. 20 July 1903. Uccle (Belgium). C. Flammarion. Les phénomènes de la foudre, p. 119.

In the vicinity of the Uccle Observatory a ball lightning the size of an egg intruded into the home of a doorkeeper, turned toward the table, circled around the top of the latter, then moved toward a small telephone, which it caused to ring, and then turned around and calmly left the same way it had entered, but not without having scared the wits out of the spectators.

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154. 4 September 1903. 10 p.m. Paris. Ciel et Terre 24, 544.

On September 4 toward 10 o'clock in the evening a heavy thunderstorm broke loose over Paris. While observing the Eiffel Tower from the fourth floor of a hotel on the rond-point of the Champs Elysées, I saw how the spire of the tower was struck by a whitish lightning flash coming from the zenith. At the same moment a fireball, which was less bright than the lightning and yellow in color, slowly descended from the spire to the intermediate platform on the third storey, where it disappeared without any explosion. It seemed to be at least 1 meter in diameter and appeared to move down the inside of the tower, whereby it took about 2 seconds to cover the distance of approximately 100 m. The next morning I visited the tower and discovered that it had in fact been struck twice by lightning on the previous evening. However, since no one was up there at the time, the ball was not noticed. It seemed strange to me that the recording anemometers, which are mounted on the spire and connected via electrical wires to the Bureau Central Météorologique, continued to operate without interruption. The watchman, who on various occasions had seen lightning strike the tower before, told me that this happened fairly frequently. If this is the case, then it should be of interest to watch the tower closely during thunderstorms, for example from the nearby Bureau Central Météorologique. Accurate observations made by scientifically trained persons would perhaps enable us to obtain more knowledge of the nature of this mysterious phenomenon and of the circumstances under which it takes place.

155. 2 December 1903. 7 p.m. Poppenweiler. A. Gockel. Das Gewitter, p. 43. Print from the Kölnische Volkszeitung.

156. 2 April 1904. 2.12 p.m. Ullersdorf. Das Wetter 21, 118, 1904.

157. 9 April 1904. 12.50 a.m. At sea (4° lat. N 30.5° long. W) on the barque Cap Horn, Capt. C. Tramburg, during the voyage from Autofagasta to Ostende. Prometheus 19, 304 and Ann. d. Hydr. 32, 1904, Issue 8, p. 390, resp.

158. 23 April 1904. 7.38 p.m. Laesgen. District of Grünberg (Silesia). Das Wetter 21, 119, 1904.

On April 23 at 3.10 p.m. a distant thunderstorm was observed. Toward 7 p.m. thunderclouds started to pile up in the west and south, and seemed

to forecast bad weather for Laesgen. Besides my family and myself, also the neighbour, i.e., five persons all told, watched the course of the clouds from the school garden. Then at 7.38 p.m. a powerful fireball moved with great velocity from the western thundercloud toward the southern one. It was the size of the disk of the setting sun and moved more or less parallel to the horizon at an approximate angular elevation of 30°. The ball did not drop toward the earth, but suddenly disappeared at the height at which it was traveling. Furthermore, the observers were blinded and could not give further details on how the ball vanished. The ball was apparently circular in shape and its contour was sharply defined. About 8 seconds after the lightning there followed a loud thunderclap. While we were left standing, astonished at the phenomenon, my 63-year-old neighbor uttered the words: "Oh, like the sun, all red, I have never seen anything of the kind in my whole life!"

Three minutes later, i.e., at 7.41 p.m., a powerful zigzag lightning was observed in the west, but only after 12 seconds was the thunder heard. In the subsequent rolling thunder we heard a short, sharp, not so distant crack, which was somewhat louder than a rifle shot. From 9.15 to 10.15 p.m. and from 10.45 to 11.00 p.m. there was still a local storm with rain (precipitation intensity 2) and from 9.21 to 9.27 p.m. hail fell.

159. May 1904. Tseria (Greece). C. Flammarion. Les phénomènes de la foudre, p. 106.

160. 16 July 1904. Autun. Comptes Rendus 139, 465.

161. 24 July 1904. Juvisy. C. Flammarion. Les phénomènes de la foudre. p. 110.

162. 22 August 1904. 11.30 a.m. —12. Dawlish (Devonshire). C. Flammarion. Les phénomènes de la foudre, p. 120.

163. 17 June 1905. Antwerp. C. Flammarion. Les phénomènes de la foudre, p. 110.

164. 30 June 1905. 7.05 p.m. Namur. Ciel et Terre 26, 246.

165. 10 August 1905. 7.30 p.m. Königsberg (Prussia). Elektrotechnische Zs. 26, 829, 1905.

On August 10, 1905, at about 7.30 in the evening, I had the opportunity to observe the following natural phenomenon:

During a short, but violent thunderstorm a bright luminous ball lightning with an apparent diameter of 20 cm appeared in the southeastern sky. The ball seemed to be stationary for a moment, then moved along a downward sloping path toward the west and burst after about 5—6 seconds, illuminating its surroundings in a reddish light. Particularly during the formation and disappearance of the phenomenon the faint noise of rapid discharges could be heard. The peculiar, and perhaps the most important trait for the study of ball lightning, was the shape of the ball. The presence of a small indentation on the left edge, from which a short shadow extended over the surface, indicated that the lightning was whirl-shaped. Seemingly, the lightning landed

at a relatively far distance from my observation site; this assumption is borne out by the red glow caused by the water-vapor-containing air layers between the spot where the ball landed and the observation site.

166. 23 July 1906. 9.30 p.m. Romont on the Freiburg — Lausanne Railroad. Met. Zs. **26**, 458.

The following accounts were taken from the minutes of the court hearing of a case in which two people were indirectly killed as a result of a lightning striking an electric-power line.

On July 23, 1906, toward 9 p.m. a very heavy thunderstorm broke loose over Romont. A member of the board of directors of the railway station gave the following report of a ball lightning which was observed during this storm:

Toward 9.30 p.m. I was called by one of my men. I walked out of my office and saw in the presence of five or six persons how greenish, very shiny spheres, which seemed to be the size of an egg, wandered along the electric wires from Nigg's house to the wood in the direction of Prevonloup (i.e., in the direction of one of the hills surrounding Romont). The spheres disappeared high up in the sky, while new ones appeared near Nigg's house and followed the same path. Others reappeared and vanished again. They wandered slowly along the wires. We observed this phenomenon for about 15 minutes. They disappeared before the arrival of the train from Bulle (9.30 p.m.).

An inhabitant of the village of Mézières (about 1 km south of Romont), where the lightning caused the above-mentioned disaster, witnessed from his house, after a powerful thunderbolt, which struck the village, a ball follow the electric wires.

In a monastery about 100 m north of the Romont railway station a monk saw a large fireball come out of a telephone. The ball disappeared immediately, but in the room a window and a pipe of the central heating system were broken.

Gockel added the following remark:

In these cases we are obviously dealing with discharges between the electric wires and the earth. The former could have acquired a voltage in the free air at the potential of the atmosphere which at the height of the wires (above 5 m above ground) could have amounted to 100,000 volts during the thunderstorm. The charging of the wires, however, must have taken place slowly, since under these conditions a significant portion of the electricity flows off into the ground via the insulators. Thus, in my opinion we have here a practical example of the case of high-voltage generation with slow charging of the electrodes — an effect which Töpler studied in his famous experiments with the induction machine and the collector electrode.

167. 11 August 1906. 5.30 a.m. Rochas near Neisse. Kosmos 1906, 309.

168. 26 May 1907. 11.00 p.m. St. Georges-de-Reneins (Rhône). Comptes Rendus, **146**, 554.

169. May 1907. 9.00 p.m. Kossmann Estate near Bleiburg (Kärnten). Met. Zs. **25**, 42, 1908.

170. 7 September 1907. 9.30 p.m. Dungass (Chad). Le Cosmos 59, 30, 1910. C.L. 62.

Toward 9 o'clock in the evening a tornado from the northeast started to form with all the characteristic properties: wind, rain, lightning, thunder. We were already outside its range, and the lightning flashes were starting to become less intensive, when suddenly I heard almost immediately after a lightning a real explosion, which consisted of a single, cannon-like detonation. At the same moment I saw a fireball seemingly descend from the sky and follow a vertical path: a luminous trail like a cable, which held the ball, appeared above it. This trail is perhaps attributable to the impression left on the retina by the fireball; however, the ball plunged relatively slowly.

171. 19 March 1909. 4.50 p.m. Antwerp. Mem. della Pontif. Accad. Rom. dei Nuovi Lincei 32, 275, 1914.

In the afternoon of March 19, 1909, a short-lived tornado struck the city of Antwerp. At 16 hr 50 min a sinister darkness started to set in, large raindrops fell, and a lightning struck the wall of St. Catharine. At the same moment the engraver Vinche saw a red, but not very luminous ball on the street; it plunged straight down as fast as a heavy body at a distance of about 15 m on the side of the belfry of St. Borromäus which is provided with a lightning rod. No sooner had the ball reached the ground than it ascended again and exploded with a loud noise like the discharge of a cannon; however, it did not scatter about streak lightnings but suddenly disappeared without bursting or causing any damage, and merely left behind a smell like that produced upon singeing. The entire phenomenon lasted about two seconds.

172. 11/12 September 1909. 1.00 a.m. Mühlhausen (Thüringen). Ergebn. Gewitter-Beob. 1908/09. Veröff. Kgl. Preuss. Met. Inst. No. 231, Berlin 1911, p. LXXII. Reprint of a newspaper article.

Near Mühlhausen a dreadful thunderstorm broke loose with cloudburst-like rain. Lightning struck the ground about 15 times, but without causing any significant damage. At night toward 1 o'clock twelve loud discharges were heard within 3 minutes; some of these were caused by ball lightnings. These had the appearance of a ball suspended on a thread.

173. July 1910. 4.30 p.m. Frankfort on Main, South. Observed by H. Daniels.

It was in Frankfort on Main, South, in July of the year 1910. I was staying at the home of my uncle which is located on the Gretenweg on Sachsenhäuser Mountain. From here there is a good view of part of the city below. In the afternoon between 4 and 5 o'clock a heavy thunderstorm with rain approached and broke loose over the city. I was standing next to the window and looked down upon the city below, when suddenly two brightly luminous balls, each the size of a head, appeared at a house in a street about 200 m away at a height of approximately 10 m above the ground (the lower portion of the house was blocked from view by another building) and rolled up along both sides of the drainpipe at a distance of about ½ meter from one another. The color of the ball was bright yellow, comparable to

that of a metal-filament lamp, but surpassing it in brightness. The contours seemed to be sharply outlined. The size corresponded to twice the width of the drainpipe. The movement of the balls could be readily followed by the eye. I called my uncle, who was sitting in the same room, to the window, but he only saw how both balls suddenly vanished as soon as they had reached the edge of the roof. Their disappearance was accompanied almost simultaneously by a detonation. — Upon further questions the observer stated the following: the appearance of the two balls was not immediately preceded by a lightning flash; also, after the balls vanished no lightning was observed. Nothing could be said of a characteristic motion owing to the great distance. The balls, which seemed to be identical to one another in color, shape, and size, did not emit sparks, either during their motion or upon their disappearance, which the observer described with the words: "All of a sudden they were no longer there." Furthermore, no other luminous phenomena were to be seen in the surroundings.

174. 3 January 1911. In the evening. Rome. Das Wetter 28, 161, 1911.

175. 5 May 1911. 12.30 p.m. Lovrana (Istria). Atti della Pontif. Accad. Rom. dei Nuovi Lincei 65, 36.

176. 9 September 1911. 12.15 p.m. St. Pellegrino. Atti della Pontif. Accad. Rom. dei Nuovi Lincei 66, 65.

At about 12.15 in the afternoon there arrived a heavy thunderstorm with lightning, thunder and precipitation. After a very vivid lightning flash, which was followed by powerful thunder, a red ball was seen rolling over the ground in a garden. Thereupon it ascended straight up into the air, then flew horizontally over the houses and finally landed in the water of the Brembo. No changes could be detected in the trees in the garden.

177. 11 September 1911. 2 p.m. Aix-en-Provence. Le Cosmos, Rev. des sciences et de leurs applications 60, 1911, C.L. 65, 341.

178. 16 September 1911. 8.15 a.m. Empoli. Atti della Pontif. Accad. Rom. dei Nuovi Lincei 65, 38.

Professor Galli communicates the following extract from a letter of the sister superior of the R. Conserv. of the Santa Annunciata at Empoli:

The thunderstorm reached Empoli at about 8 o'clock in the morning. At 8.15 the sisters and schoolmistresses, who were having breakfast in the dining hall, saw a ball red in color and about 12 cm in diameter enter. It created the impression that (as had been observed before on frequent occasions) the ball carried out somersaults (danced up and down) and other jumps, which were attributed to illusions caused by fright, "so that one child said and maintained that he saw the red ball fall into his coffee cup." However, it is certain that upon leaving the dining hall in the direction of the kitchen the ball encountered a sister on the doorstep who was carrying a cup on a porcelain plate. The lightning broke the plate into two pieces without injuring the sister. In the kitchen two cooks (also sisters of the convent) saw it leave via the open window and hurl flames about in the

open air. From there it made its way to a small belfry, which was about 15 m away, and exploded there with a frightning noise. In so doing, it damaged, although only superficially, the belfry as well as the small dome of the church which was attached to the building of the institution; pieces of stone and plaster were strewn over a fairly large area. Furthermore, it melted the electric power lines below the bells in the belfry without damaging the bells themselves.

However, before the ball intruded into the dining hall, it must have wandered through the house, since it followed the electrical wires and because it was also observed on the steps leading to the choir, where it caused a lot of smoke and burned the small lamps. The same happened in the sacristy and in other places in the building. The sisters and schoolmistresses experienced no further discomfort other than an indescribable fright.

179. 4 October 1911. 3.15 p.m. Monte Mario Monastery near Rome. Atti Pontif. Accad. Rom. dei Nuovi Lincei 65, 40.

180. 15 October 1911. 2.30 p.m. St. Francesco Monastery at Monte Mario near Rome. Atti Pontif. Accad. Rom. dei Nuovi Lincei 65, 40.

181. 12 May 1912. 6.45 p.m. Plaven near Dresden. Met. Zs. 29, 384, 1912.

A remarkable ball lightning was observed on May 12, 1912, at 6.45 p.m. from the 200-m-high section of Plaven near Dresden on the adjacent side of the narrow Weisseritz Valley. Although the observation site itself lay beyond the range of the thunderstorm (the nearest of the three thunderclouds was at a horizontal distance of 3 km), suddenly, without there preceding a lightning of some other form, there appeared at a height, which must have been less than 100 m above the ground, a luminous spherical mass at a distance of approximately 1 km from the observation site. The instant that one of us first noticed the luminous phenomenon there was a second, smaller ball about 1.5 m below the first which was connected to the upper ball by a fine strip similar to a string of beads. The color of the balls was reddish yellow (about 600 $\mu\mu$). Both moved slowly one directly above the other in the direction northeast, whereby the upper ball maintained a constant height above the ground, while the lower one slowly descended as the connecting luminous strip faded. At the observation site the wind came from the north. As soon as the lower ball was to within a short distance from the ground it continued to move in the same way as the upper one.

Both balls had a velocity which could hardly have exceeded 1 m/sec. The lower luminous ball soon vanished behind a bush; from its height, distance and angle, under which the upper edge of the bush could be seen, we concluded that the diameter of the lower ball could not have been greater than 1 m. The upper ball suddenly faded shortly after it, and likewise started to follow a downward sloping trajectory. No noise was perceived, and the total duration of the event from the moment the phenomenon was noticed to the instant the upper ball faded amounted to two minutes; the movement of the lower ball close above the ground lasted about $^3/_4$ minute ...

182. 13 June 1912. 5 p.m. Leitmeritz. Das Wetter 29, 188, 1912.

On June 13, 1912, at 5 p.m., during a thunderstorm which passed over Leitmeritz from the southeast and which was accompanied by numerous electrical discharges and a heavy downpour, a ball lightning was observed in the "Elbschloss" brewery in Leitmeritz. The lightning struck the high stack of the brewery, jumped from a wire onto the ground, moved in the form of a red ball the size of a goose egg a few meters over the ground and then suddenly burst with a detonation-like noise, leaving a strong odor of sulfur. No damage was caused by the lightning. Several eyewitnesses stated concurrently that this ball lightning moved with remarkable slowness. The phenomenon lasted at least 5 seconds.

183. Summer 1912. Compiègne. Das Wetter 30, 21, 1913.

184. 2 December 1912. (3 p.m.?). Tissey (Yonne). Comptes Rendus 155, 1567.

On December 2, 1912, at 1 o'clock the sky over a village 8 km from Tonnerre (Yonne) to the north of Tissey became overcast after a rainy morning, which was followed by a long period of clear sky. Soon a storm with rolling thunder and lightnings broke loose over Tissey, a very dense rainfall drenched the soil and then the storm seemed to calm down. It was about half an hour after the last thunder had been heard; the wind had died down, the sky was uniformly covered with cloud, the rain fell steadily; suddenly a heavy thunder was heard which was immediately followed by a most powerful discharge, which extended a distance of 1 km over the entire village.

Over the largest part of Tissey and simultaneously at all points bursts of fire spouted out of the ground. Above a water reservoir, which was supplied by a subterranean water layer, the discharge took on the form of a sphere three times the size of a head and was completely separated from the water surface. At the same moment a laborer, who was standing in a shed 100 m from the water reservoir, saw a head-sized fireball pass down the street at a distance above the ground corresponding to the height of a man of average height. The appearance of the ball was, so he said, separated from the observation of the ordinary lightning, which he saw an infinitely short but noticeable time after the fireball. Outside the village the discharge had melted a steel wire, which was stretched over a hay stack and anchored by two large stones, over a length of about 15 m and caused a fire to break out there, which, however, was quickly extinguished by the rain. The ground was uprooted over a length of 2—3 m and to a depth of 5 cm at the points where the wire ends, dragged along with the stones, fell. The discharge was followed by a downpour accompanied by hail and snow.

The above facts indicate that the appearance of the ball lightning was not due to circumstances whereby the position of the observer had caused him to see a zigzag lightning straight on. A comparison of the present case with that observed at Strassburg on the Rhine in 1869 and described by Ch. Hugueny points to the similarity of the prevailing conditions and the presence of subterranean water below the sites where ball lightnings were observed.

185. 9 April 1913. 11.30 a.m. Atti della Pontif. Accad. Rom. dei Nuovi Lincei 67, 112.

186. Summer 1913. Marienfelde near Berlin. Das Wetter 30, 213, 1913.

187. 23 July 1913. 1.12 a.m. Mailand. Mem. della Pontif. Accad. Rom. dei Nuovi Lincei 32, 278, 1914.

At 1.12 a.m. on July 23 I was still standing at the window on the top floor during a thunderstorm, which was passing over the city. I was hoping to see once the appearance of ball lightnings, such as had occurred in the year 1904. Then, finally, I saw a ball bathed in a most beautiful orange light, which was more vivid in the center, such as is always the case with luminous balls without aureoles; the ball was surrounded by a sharply outlined, sky-blue ring. The diameter of the ball was 10 or 12 cm and the the circular ring had a width of about 3 cm. The boundary between the orange color of the ball and the sky-blue of the ring was very sharp, i.e., without any mixing of colors. However, in the vicinity of the outer edge the intensity of the sky-blue coloring decreased over a width of about 1 cm, so that the contour seemed less sharply defined. The ball first rolled down a drenched roof, then made a ninety-degree turn and jumped successively onto the tops of four brick chimneys projecting above a wall opposite the window of the observer. It remained at rest for an instant and then jumped onto a chimney top, which consisted of metal and was higher than the other chimneys. No sooner had it come into contact with this chimney than it leaped up into the air and burst with a cracking noise and a dazzling light. It had taken five or six seconds to cover a distance of about 12 m; no damage was caused.

188. 17 January 1914. 11 a.m. Luogosanto (Province of Sassari). Atti della Pontif. Accad. Rom. dei Nuovi Lincei, p. 290, 1914.

189. 22 March 1914. 8.30 p.m. Poggio-tre-Croci near Viterbo. Mem. della Pontif. Accad. Rom. dei Nuovi Lincei 32, 276—278, 1914.

Shortly before 20 hr 30 min in the evening, about 200 m from the church, a luminous ball, which vanished and reappeared several times, was seen in the air. Four minutes later the priest, three members of his family and another gentleman, who were gathered around a table, saw a small ball hardly larger than an egg yolk (about 2½ cm) oscillate up and down in the glass chimney of a kerosene lamp, which was burning in the middle of the table. This ball, which performed at least three oscillations in the above-described manner, was dark grey in color over the lowest third portion (probably due to the soot from the flame), but in the remaining upper portions possessed vivid colors, which under a predominance of green were comparable to the colors of the rainbow and which passed in disorderly fashion through one another. The top glittered in an intense orange light. Each time the ball descended toward the flame this light became weaker. Hardly one second after the ball had escaped through the top of the glass chimney a dreadful, harsh thunderclap occurred which was also heard in very remote villages. A very strong surge of air was produced which,

instead of extinguishing the flame in the lamp of the priest and in all the other kerosene lamps in the small village, caused them to light up intensely. Those, who were in the streets, heard a loud bang, became frightened and fell to the ground. All the window panes broke and even the tiles on the nearest roofs cracked. The small ball had burst at the front of the church, which adjoined the priest's dwelling; it tore off the iron cross and the steeple of the belfry; here it ripped a 7-m-long and 1—2-m-wide hole, hurled the doorposts a long distance and destroyed the main part of its arch, splintered and burned the window bars (primarily the top portion thereof), destroyed the left corner of the church front 8 m away, shattered even the dome of the choir on the roof and loosened its base.

When the priest had recovered from his fright, he ran into the church and found it filled with dust, which was mixed with a malodorous, stifling smoke, similar to that produced when a mine explodes. Inside everything had been broken and destroyed. Both inner doors were smashed and all the glasswork was broken, even in the sacristy. The steel curtain rod was bent in a peculiar way; some of the gilding was scratched off, lamps and artificial palm branches were strewn over the floor, the walls were cracked, all the plaster ornamentation and stones had fallen down; however, to the great surprise of the priest, the cement floor was neither cracked nor chipped by the impact of the large falling stones, "as if the lightning had carried them softly down." Not one of the lamps which were strewn over the ground showed any sign of damage or impact.

190. 30 April 1914. 4.30 p.m. Saint Georges-d'Aurac. Comptes Rendus 158, 1542, 1914.

19[illegible] 12 June 1914. 6 p.m. Wächtersbach. Prometheus 25, 762.

On Friday, in the afternoon of the 12th of this month, shortly after 6 o'clock, a lightning struck the lightning rod, which was mounted in a pyramidal oak tree. This tree stands at a distance of 20 m from the 14-m high local castle and itself has a height of 27 m. I feared that this tree, perhaps the most beautiful of its kind, might be struck by lightning streaks. Consequently, three years ago I installed a platinum-point lightning rod which projected slightly above the tree. Besides safety fuses for the electrical lighting and ground leads for the public and private telephone, including overhead lines, the castle proper and its surrounding structures are not provided with lightning rods. Lighting, telephone and bell wires, as well as gas and water lines run criss-cross through the castle. Ever since the lightning rod was installed in the tree it has been struck by lightning during almost every thunderstorm. The rod is grounded very well, since it is connected via a finger-thick copper cable to the extensive castiron water-line network only 18 m away. From this time on lightning no longer struck the lovely trees in my castle garden which earlier were decimated due to this cause.

The lightning stroke on the 12th of this month was closely observed at a distance of about 22 m by a servant standing at an open window of one of the ground-floor rooms. The instant the lightning struck, a large number of small flames shot out of the point of the lightning rod and described an arched path toward the ground. One of these flamelets, a zigzag discharge of 30 cm length, which looked exactly like the sparks produced by a large induction machine, flew in through the window, past the observer and

disappeared in the telephone about 15 m away. The spark covered this distance in 5—6 seconds, while maintaining a constant height of 1½ m. At the same time a similar spark penetrated via a slit in the closed window into my living room two stories higher, traversed it likewise at a height of 1½ m above the floor, entered into the anteroom, searched like a mouse for a narrow opening below the closed door and disappeared through it. Behind this door is the bathroom with large water pipes, which this electrical discharge probably sought out. It covered the visible part of its path of about 12 m in approximately 4—5 seconds and moved between two telephones, passed a large metal chandelier and a number of wires and pipes ...

192. 22 June 1914. 6—6.30 p.m. Hahnenklee (Oberharz). Met. Zs. 32, 22, 1915.

On June 22, 1914, a ball lightning penetrated into the glass-framed veranda of the Schwenzel Hotel in Hahnenklee. Mr. Kuhlgatz, the local school inspector in Kiel, who had observed the phenomenon from very close by and added further details concerning the local conditions after making a second trip in September to the above-mentioned hotel, was kind enough to communicate the following information:

Mr. Kuhlgatz was sitting between 6 and 6.30 o'clock in the evening on the above-mentioned veranda; his chair was positioned such that the long glass partition of the veranda was to his left, i.e., his line of sight was directed toward the fairly distant side partition which closed off the veranda. Two other persons were sitting at his table, and at another table in front of him there was a second group of guests. While all the windows were shut and the rain was pouring down outside, Mr. Kuhlgatz suddenly saw ahead to his left a fireball about 10—15 cm in diameter penetrate via the upper window into the veranda and move around with moderate velocity. After a few moments there followed a cannon-like discharge. The second group of guests, who were sitting directly below the path of the ball, jumped up from their seats. In the guestroom adjoining the veranda there was a rinse-basin next to the bar which was connected to a water pipe about 1 m away. According to another guest, who was standing next to the bar, the path of the fireball was observed in the direct vicinity or inside this basin. The fireball left no traces whatsoever on the walls of the veranda or in the guestroom. On the other hand, the telephone, bell and electrical-lighting wires of the house were heavily affected. They were in part destroyed and in some places fused. All the electrical lamps went out and the bell rang incessantly. No ozone- or sulfur-like smell was perceived. Several minutes later an intense, strongly twisting zigzag lightning flash was observed on the side of the windows.

The question is how the ball lightning entered the veranda and the adjoining room. According to direct observation, the ball had penetrated through the window partition of the veranda, which was everywhere closed, and passed from here into the guestroom, which was likewise closed off by a wood-paneled partition with inlaid windows. In neither of the two partitions were there any openings or perceptible slits between the window panes. The telephone and electrical-lighting wires are suspended outside at a point on the house wall, which projects considerably above the veranda, about 1½ m above the veranda roof which is covered with roofing felt. This point is about 6 m away from the point at which the fireball entered. All the wires

in the veranda come from within the house and in part run along the wall and in part along the ceiling; there were no wires along the window partition of the veranda. Thus, the ball lightning had passed through a tightly closed partition consisting of wood panels and windows without damaging the latter in any way.

If we wish to understand the causes behind this extremely remarkable event, then it seems that we are left only with the following explanation. The wires running through the guestroom and the veranda acquire a very high charge from the overhead lines leading to the house. This charge gave rise to the creation of spherical, luminous and exploding formations on the veranda as well as in the guestroom. Qualitatively, this can be correlated with other experiences. Here we will merely assume that quantitatively the balls which jumped from the electrical wire must have possessed an uncommon size and explosive power. Of course, in this interpretation we must assume the possibility of a slight hallucination of the observers, insofar as the path of the ball did not start on the window side. I am of the opinion that the second interpretation is the more probable one.

193. July 1914. Adendorf (Hannover). Das Wetter 31, 215, 1914.

During one of the last storms of July the family of Baron von der Decken had a peculiar experience in Adendorf (Hannover). The family was sitting during the thunderstorm in question in the living room, when suddenly a powerful shock caused the whole house to shake. Immediately thereafter the frightened members of the family heard a strange noise above their room and at the same instant a ball the size of a goose egg appeared on the ceiling, fell relatively slowly down along the window curtain and finally vanished into the floor. The ball lightning had at no time set the curtain afire. Only above on the ceiling could a dark spot of burnt wood the size of a pfennig be perceived.

194. 21 August 1914. 9.10 in the evening. Frankfort on Main. Das Wetter 31, 240, 1914.

195. Autumn 1913 or 1914. 6 p.m. Treysa (Hessen-Nassau). Observed by Suntheim.

On an autumn day of the year 1913 or 1914 I saw at 6 o'clock in the afternoon, during a thunderstorm approaching from the west, a bluish red ball lightning from our house in Treysa which has an unobstructed view to the west. It seemed somewhat larger in size than a full moon; several indentations along its edge could be clearly recognized. The storm was not very heavy and rain did not fall until a quarter of an hour after the appearance of the ball lightning. The ball lightning was visible for approximately two seconds and moved along a straight path at a downward slope of about 30°. Its point of origin lay in one of the higher clouds and it disappeared in a lower-lying cloud. Thereupon followed a weak thunder. Shortly thereafter the storm died down completely.

196. 15 Aptil 1916. 6.30 p.m. Puy de Dôme. Monthly Weather Review 44, p. 516—517, 1916.

197. July 1915. 5 p.m. Kirchhain near Marburg. Observed by district judge Wagner and son.

In the afternoon of July 1915, toward 5 o'clock, a violent thunderstorm broke loose with numerous powerful discharges over Kirchhain and its
86 surroundings. My father and I were standing at a window of the district court house, which is located at the northern end of the city; from our vantage point we had an unobstructed view to the north. Suddenly, about 300 m away at the height of a house, we saw, without first noticing a lightning flash, a luminous ball, which apparently came from the clouds and moved at low velocity along an inclined trajectory toward the ground. At the same time the already heavy rain became more intense. The ball had the size of a full moon, was dazzling white in color and was clearly visible. It did not possess a sharply defined contour but rather formed protrusions to all sides during its motion. It vanished in the air just as noiselessly as it had appeared. The entire process lasted about three seconds.

198. 3 July 1916. Tanne (Harz Mountains). Met. Zs. 33, 475, 1916.

Many observations of ball lightnings have emphasized that the phenomenon is preceded by an ordinary lightning streak, so that the opinion has become widespread that as a sort of condition for the formation of a ball lightning there must be an "initial lightning" associated with it. However, on Monday, July 3 of this year, I observed in Tanne a ball lightning, which was preceded several minutes by other lightning streaks, which three minutes after its exploding was followed by a powerful lightning stroke, which struck directly behind the building in which the ball lightning had occurred and also set fire to the place where it struck. The ball lightning burst with an abrupt explosion, which sounded as if a cartridge had been fired off a few meters in front of the house. At the same time all the electrical lightbulbs and fuses of the electrical-lighting wires of the house blew, whereby a cylindrical luminous mass, freely hovering downward through the air, seemed to form around a light bulb directly in my line of sight; nevertheless, I regarded this as some kind of subjective image, simulated by the movement of the eyes while the bulb burnt out. The actual ball lightning occurred in an adjoining room, where it entered via a stovepipe in the presence of three persons in exactly the same way as had happened two years earlier. The repetition of the phenomenon leads to the presumption that the local conditions are particularly favorable for the formation of ball lightnings.

199. 16 August 1917. 8.30 o'clock. Jambol (Bulgaria). Das Wetter 35, 130, 1918.

In the evening of August 16, 1917, after a very hot day (the maximum air temperature of the day was 37.4° C), a violent thunderstorm occurred. Rapidly approaching from the NW it reached the zenith at 8.25 p.m. At the
87 same time (after the passage of a squall with windspeeds exceeding 35 m/sec) discharges of rare intensity began to manifest themselves. Only a few lightning discharges reached the ground; however, uninterrupted streams of sparks, which seemed to form a fiery grating in the sky, passed between individual cloudmasses. At 8.30 p.m. the peak of the thunderstorm's activity was reached, and 200 or more lightning flashes per minute could

be counted. Strangely enough, even at this stage lightning struck the ground with relative rarity. Only in the SE did such discharges occur frequently; these gained in intensity and repeatedly followed the same path which is probably due to the increased conductivity of the air along this channel. After another, very powerful discharge, there immediately followed a beaded lightning along the same channel. The individual luminous points were identical in shape and increased in size, without changing their position relative to one another or in space, until they became invisible owing to the rapidly decreasing light intensity. A few seconds later a lightning discharge followed the same channel. Shortly thereafter, at the upper end of the discharge channel, just below the cloud cover, a spherically shaped luminous mass appeared which descended at low speed toward the earth, so that it could be clearly recognized as a free-falling ball along its entire path to the ground. A short time later, also after a powerful lightning discharge, the phenomenon repeated itself. In this case, however, the movement of the luminous mass was too rapid for a reliable assessment of the ball's shape. It created much more the impression of a disk, whose intensity decreased slowly toward the outer rim from the inside as it descended earthward.

Toward the end of the storm several further observations of discharges similar to ball lightning were made. Numerous horizontal lightnings passed from a cloud in the SE over to one in the NW in the direction of the observer. After each powerful discharge a bright luminous ball, whose diameter was approximately three times the width of the lightning, could be seen at the end of the lightning channel facing the observer. It persisted almost a second at this point and then split into seven to nine raylike, downward streaking lightnings. Whether this was a genuine manifestation of ball lightning or whether the lightning was observed as a pointlike light phenomenon owing to the position of the discharge channel, could not be established. From other sources several observations of ball lightnings were also reported. On the whole, these accounts agree with the above description, so that it is hardly necessary to cite them here, the more so, since they relate to events that occurred in the immediate vicinity of the observation site.

200. St. Cyr. Le Cosmos 46, 1897, N.S. 37, 95.

In St. Cyr someone (Cunisset-Carnot) saw from a window how a ball, not consisting of fire or light but rather of glittering reflections, passed along the rim of a roof on a nearby building. This ball moved at a velocity of about 2 m per second. It soon reached the bottom of the sloping roof, passed along the gutter and fell off the far end behind a wall. Its arrival on the ground could not be established with certainty by the observer, since this point was blocked from his view. However, the instant the ball must have hit the ground a powerful thunderclap was heard which seemingly originated from this point. No trace of the passing meteor could be discovered.

201. a) Bourbonnais. Le Cosmos 46, 547, 1897, N.S. 37.
b) Haubourdin near Lille.

The following two examples of ball lightnings were related to me by eyewitnesses who could not have been mistaken.

a) The first case was described to me by one of my aunts, Mrs. de B. She was staying in Bourbonnais (Champagne) in a room on the ground floor; the window was open. In the middle of a thunderstorm she saw how a large fireball entered via the door, slowly wandering in over the floor, came closer and turned about — "like a cat rubbing itself along the leg of his master" — then made its way to a chimney through which it disappeared. This happened in broad daylight.

b) The second case took place in Haubourdin near Lille in the castle of Count de Herbigny. The dwelling also comprised a courtyard of the old castle with meter-thick walls. One evening, toward the end of a most violent thunderstorm, a large fireball was seen as it intruded via a window at the upper end of the yard and disappeared around a corner in the corridor. However, immediately afterwards a detonation was heard which was comparable in strength to several cannons. The ball had caused extraordinary effects. The thick courtyard was cracked over a length of several feet.

202. Beugnon. C. Flammarion. Les phénomènes de la foudre, p. 18. Literal translation from an article in L'Assoc. franç. pour l'avanc. des Sciences.

A heavy thunderstorm had broken loose over the community of Beugnon (Deux-Sèvres). At the time I was in a farmyard together with two children
9 of 12 or 13 years of age. The latter had taken shelter from the rain below a door of a stable, which housed 25 head of cattle. In front of the stable there was a sloped yard which stretched 20 m to a large slough, where a poplar stood. Suddenly a fireball the size of an apple appeared at the top of the poplar. We saw how it descended from one branch to another and followed the trunk down to the ground. It rolled very slowly over the ground in the farmyard, whereby it seemed to search its way between the water puddles. It then arrived at the door, below which the children were seeking shelter. One of them had the courage to nudge the fireball with his foot; there immediately followed a dreadful crack which shook the walls of the farmhouse. Both children were knocked to the ground, but were not injured; in the stable, however, eleven head of cattle were killed.

203. Date and locality not specified. During the night. Comptes Rendus 111, 493.

In a report concerning fireballs, which were observed during a tornado in St. Claude, the reporter related the following "family memories":

During a heavy nocturnal thunderstorm a fireball penetrated, probably via the chimney, into a servants' room, which was next to the room into which my mother and sister had fled. They did not see this ball, but heard how it rolled about with a loud rumbling noise. Fortunately, the maid, who had gone to bed, was so fast asleep that she was not woken up. After a few moments, which seemed like ages, the ball slipped under the door, whereby it tore off some wood shavings, of which I later found traces; then we heard how it passed through a long corridor and turned to a window, which looks out upon a much lower-lying yard. It broke the corner off one of the window panels and dropped onto an almond tree, which it demolished with an explosion. The phenomenon was so frightful, or at least the excitement caused by it was so great that my sister remained as pale as death for weeks.

204. No date. C. Flammarion. Les caprices de la foudre, p. 86. Paris.

205. Secondigny (Deus-Sèvres). C. Flammarion. Les caprices de la foudre, p. 88.

206. 10.30 p.m. Lalande de Libourne (Gironde). C. Flammarion. Les caprices de la foudre, p. 92.

207. Marseille. Sestier. De la foudre, de ses formes et de ses effets, 1, 123.

Seven persons were gathered during a heavy storm in the living room of a country house near Marseille, when they suddenly witnessed the appearance of lightning in the form of a dish-sized ball. The ball moved toward an 18-year-old girl, who had dropped to her knees out of fright, touched her feet, rebounded up to the ceiling and then moved in fairly regular fashion three or four times up and down, whereby it alternately struck the ceiling and the feet of the young girl; during this time the latter experienced nothing else but a slight cramp in her legs. Those who witnessed this phenomenon suffered no injury. The fireball disappeared via the keyhole. As regards the young girl, she could not immediately get onto her feet. For more than a fortnight she could walk only when supported under the arms, and for longer than two years afterward there were moments at varying time intervals in which she would suddenly feel weak and drop to the ground, when there was no one in the vicinity to support her.

208. No date. Gorges du Loup near Nizza. La nature 29, 1901, 2nd Sem., p. 561.

It seems appropriate to report an incident witnessed by my father — an engineer — and three of his friends, whom I can identify by name. It was several years ago in Gorges du Loup, at the time the railway section connecting Grasse and Nizza was under construction. The weather forecasted a storm and heavy raindrops started to fall. My father and his friends were having breakfast in a room of the hotel "Gorges du Loup"; the window was open. Suddenly, driven by a gust of wind, a fireball about 20 cm in diameter intruded into the room, in which the friends were sitting. The fireball, which swayed slightly and seemed to float in the air, circled around the room like a soap bubble, without touching any object. Entrained by an air current, it went out through the window again before my father and his friends, who were understandably agitated, could attempt to run away. The phenomenon had lasted for probably ten seconds. The men watched the course of the mysterious ball. Driven by the wind, it traversed in one minute the distance between the hotel and the rocky slopes above the river Loup. The instant the meteor struck the slopes there sounded a dreadful explosion. A roaring noise, such as produced by a powerful thunderclap, shuddered through the air. Then everything was quiet; the fireball had vanished.

209. Hautefeuille. Comptes Rendus 44, 871, 1852.

Regarding a report of Arago concerning a noteworthy lightning, Séguier gave the following account:

Several years have already passed since lightning struck in Hautefeuille in the canton of Charny, Department of l'Yonne. The thunderstorm rumbled for some time, but it had not yet started to rain; suddenly lightning struck a sturdy oak tree, ripped the bark off the trunk, the wood of which was dried up and split owing to a large number of lightning streaks. Meanwhile, the lightning assumed the form of a fireball, rolled along the ground, made its way toward the yard of a farm more than 300 m away, threatened to enter a shed and plunged somewhat behind the fence into a trough, where the fireball disappeared. It was spinning very rapidly and strew about soil from the furrow it channeled in the ground, whereby it left a trail of burnt grass. The diameter of the ball appeared to be about 50 cm; it left no smoke trail. According to eyewitnesses, insofar their agitation enabled them to asses the time, this magnificent, imposing spectacle lasted for more than a minute from the instant the lightning struck the oak until the fireball vanished in the trough.

210. Paris. Comptes Rendus 35. 2—3, 1852.

After a few general remarks on ball lightning the following is said:

The following report to the Academy concerns a case of ball lightning which the Academy had entrusted me to investigate several years ago. Not on the downward stroke but rather during its return stroke, so to speak, the lightning in question struck a house in the Rue St. Jacques next to the Val-de-Grâce church; in fact, this took place in a proximity which would have led one to think that the house should have been protected against this sort of mishap by the high lightning rod mounted on the dome of the Val-de-Grâce church. The following is a condensed version of the account given by the tailor in whose room the ball lightning descended and then lifted upward again.

Somewhat after a very powerful lightning stroke, the tailor, who was sitting next to his table after having finished his meal, suddenly saw how the paper-lined frame covering the fireplace opening fell down, as if it had been knocked over by a strong gust of wind, and a fireball the size of a child's head gently entered via the opening and slowly wandered about the room at low level over the floor-tiles. According to the tailor, the fiery ball appeared like an average-sized young cat which had rolled itself into a ball and moved without using its paws for support. The fireball was shiny and luminous rather than hot and inflamed, and the tailor experienced no heat sensation. The ball approached his feet like a young cat, which wanted to play and, as is customary for such animals, to rub itself along the leg of its master. The tailor nevertheless withdrew his feet and by means of several careful, or in his own words, very gently performed movements, he avoided making contact with the phenomenon. The latter seemed to pause several seconds beside the feet of the seated tailor, who, bending somewhat forward, watched it attentively. After the ball had carried out a few movements in different directions, but without veering from the center of the room, it lifted straight upward to the level of the tailor's head, who sat upright again and sank back into his chair in order to avoid being hit in the face and at the same time to be able to follow the course of the phenomenon. When the fireball had reached a height of about 1 m above the floor, it became somewhat elongated and made its way along a slanted path toward a hole about 1 m above the upper cornice of the fireplace. This hole served to accommodate the pipe of a stove, which the tailor used in winter. However,

the lightning could not, in the tailor's words, see the hole, since the latter was covered with paper. Nevertheless, the fireball went straight toward this hole, peeled off the paper without tearing it and ascended the chimney. Thus, after it had taken the time (the mode of expression used by several eyewitnesses) to climb up the chimney at the same speed, i.e., fairly slowly, as when it had come and had reached the mouth of the chimney, which was at least 20 m above the ground, it produced a dreadful explosion, which destroyed part of the chimney and hurled the broken pieces into the yard. The roofings of several smaller buildings caved in, but fortunately without any disastrous consequences. The tailor's dwelling was situated on the third floor, i.e., not at midheight of the house. The lightning did not reach the ground floor. The motion of the luminous ball was at all times slow and steady. Its lustre was by no means brilliant. Furthermore, it did not radiate any noticeable heat. The ball did not seem to have any tendency to follow conducting bodies or to veer away from air currents.

211. 7 September 1918. 11 p.m. St. Michel near Brugge. Das Wetter 36, 29—30, 1919.

On September 7 I observed in St. Michel near Brugge for the first time a phenomenon during a thunderstorm which in my opinion was a manifestation of ball lightning. Toward 6 p.m. a heavy storm approached from the SW. The first thunder was heard at 6.45 p.m. and was followed by a heavy downpour until 7.30 p.m. The storm was strikingly rich in lightning discharges, which, however, were accompanied by only moderate thunder, since the largest portion of the discharges took place at great heights initially in the form of sheet lightning. The first thunderstorm was followed at 9 p.m. by further storms, accompanied by powerful and numerous electrical discharges, the latter now occurring in lower cloud layers. At 11 p.m., as I was on my way to my quarters in a castle near St. Michel, the lightning was flashing in the sky with a vehemence such as I had never experienced before during my four-year stay in Flanders. In the castle, as I was about to enter my room, which was situated at the end of a corridor approximately 20 m long and 3 m wide, I suddenly heard an unusually violent detonation directly behind me which was immediately followed by a very bright glow. As I turned around I saw about five paces ahead of me on the ceiling of the corridor a hovering ball-shaped mass, which emitted a very bright, whitish to bluish light. The contour seemed to alter its shape; details of its shape could not be distinguished owing to the high intensity of the light. The speed at which the luminous mass descended was moderate (not exceeding 2 m/sec, according to my estimates) and followed a straight, upward path. The instant the phenomenon touched the ground it vanished into thin air without a bang or noise and without leaving behind any ozone-like odor. When I closely investigated the floor, I could not find any sign of burning; on the ceiling, however, there was a black spot on the white paint. A few seconds afterwards a violent lightning discharge struck nearby; the electric lights sputtered and sparked, the switches burnt out and the lamp sockets melted and fell down. This discharge, however, evidently occurred independently of the first one. I could not establish from where the lightning had come, since I had followed its course only from the ceiling of the corridor to the floor; it is, however,

probable that it entered via one of the numerous windows on the side of the castle which had all been broken at the time of the explosion of the ammunition depot in Steenbrugge.

212. 20 June. Helgeraaen near Larvik. Met. Zs. 25, 314, 1908.

Dr. K. Nielsen, Larvik (somewhat to the west of the mouth of the Kristiana Fjord) sent me the following communication:

During a thunderstorm (on June 20) an elderly woman was sitting in her room in Helgeraaen near Larvik. She saw a large ball, larger than a man's head, enter via an open window and move at moderate speed through the room in the direction of the stove. The ball passed right over a table, without touching any of the small objects on it, and came so close to the woman that she instinctively bent sideways. The ball was luminous, "really beautiful." It contained colors of the rainbow. When it arrived at the stove it exploded, so that the woman thought that the house would be blown to pieces. The ball was also observed by a grown-up maid, but she could not give any information since she felt faint. Both were left unscathed. Less fortunate were a young woman and her child, who at that moment were in another room near the stove, which discharges its smoke into the sole chimney of the house. When the explosion took place, both persons lost consciousness and recovered only after a while. Both could point to streaks and jagged lines on their skin caused by the sparks. The chimney on the roof of the house was half broken off. Most of the window panes were smashed. All stoves were dismembered, the stovepipes were in part ripped off and strewn about along with ashes, soot and limestone. The stove wall was cracked and exhibited holes in several places, the floor was in part broken up, the tapestry torn off the wall and the walls were scorched in several places. A waistcoat, which was hanging on a hanger, caught fire. The same upheaval applied to the kitchen and to all the other rooms on the first and second floor. It was remarkable that fire did not break out.

Kristiana, 27 June 1908 H. Mohn.

213. 25 July 1919. Lübeck. Bremer Nachrichten 26 July 1919.

214. 14 May 1919. 9.50 p.m. Dublin. Nature 103, 284, 1919.

215. 1893. Afternoon. Zürich. Observed by E. v. Maack, Altrahlstedt.

In the year 1893 we lived on the first floor of a fairly high house on Zürich Mountain in Zürich. An existing telephone line was not used, since a telephone was lacking. I did not wish to have one, since during heavy thunderstorms sparks used to come out of it. One afternoon, during a thunderstorm, I was in the room in question and witnessed a strange phenomenon. After a very powerful lightning stroke a somewhat flashing fireball the size of a large ball, such as children play with, appeared on the wooden floor next to the window. The fireball must have come out of the telephone line, even though I did not observe this. It moved vigorously and restlessly around the floor, somewhat like a frightened ant running about excitedly, and followed a smooth circular path quite slowly, as if it were rolling, but this is not certain. It then vanished without leaving a trace. Unfortunately, I did not establish how long it was present in

the room, but this could have been about three quarters of a minute. I already mentioned that it was luminous; however, smoke, steam or any other emanations detectable by our sensory organs were not produced. The ball disappeared suddenly, without any decrease in its size or any kind of noise. There was also no noise while it was circling around; I considered it dangerous to touch it and thus left it alone.

96 *PRACTICAL EXPERIENCE ON BALL LIGHTNINGS*

STATISTICS

Ball lightnings and meteorological conditions

It seems obvious that ball lightnings would occur only as a result of a thunderstorm. This, however, should be explicitly established, since, as was already mentioned in the Introduction, Galli, for example, considered the occurrence of ball lightning under fair-weather conditions as quite possible and even probable.

Taking into account only those reports in which explicit mention is made of a thunderstorm, during which the ball lightning was observed, i.e., not those reports, whereby the ball lightning appeared more or less simultaneously with lightning and thunder, there are 75 cases in which mere reference is made to thunderstorm conditions, while in 79 cases the thunderstorm is described as being heavy, violent, extraordinarily violent, or of a force never before experienced, etc. In six cases (21, 26, 36, 45, 103, 170) ball lightning appeared during strong gales. When in a few reports it seems that the ball lightnings in question were not observed at the same time as the storm — 66: there was no sign of a thunderstorm; 28: the weather was warm, the sky overcast, but there was no sign of a storm — we can consider this as signifying that these assertions refer to the period prior to the appearance of the ball lightning. This is borne out by the fact that in 28 it is explicitly mentioned immediately thereafter that a dazzling lightning flash had struck, and in 66 the ball lightning constituted the first discharge of the thunderstorm and was soon followed by a second one.

In numerous cases no reference whatsoever is made to the meteorological conditions. The accounts either start with the moment the fireball became visible or are so unspecific as regards the accompanying electrical phenomena that they are of little significance in this respect. Thus, we read in 186: the sky was overcast; 122: an exceptionally heavy downpour caused me to look out through a window; 123: the sky was clear, there were only scattered raindrops.

97 The above-established fact that in more than half of all the cases the ball lightnings are encountered as a result of heavy, violent thunderstorms will be further borne out by an investigation of the incidence of lightning in these thunderstorms. For this we shall use 20 thunderstorms mentioned in the present collection: 21, 23, 25, 29, 31, 38 a, b, c, 63, 72, 83, 103, 133, 145, 159, 172, 182, 199 (200 or more lightning flashes per minute), 211. Also in other cases, which are not mentioned in the present compilation, ball lightnings were observed during storms exceptionally prolific in lightning discharges: 5 July 1891 (Mitteilungen Nat. V. Steiermark 28, 348 and 334, respectively); the number of lightning discharges in the Gail Valley reaches the thousands between 8 and 10 p.m. 22, 23 August 1891

(ibid 28, 349): during this night lightning struck Brückl 17 times; two ball lightnings, which seemed to come from the foot of a nearby mountain, were seen.

On the other hand, fireballs also occur quite frequently during thunderstorms which are noteworthy for their few, though mostly very powerful discharges. There are nine such cases. 28: only one discharge; 46: only three successive lightnings at short intervals; further, 48, 55, 62 a and b, 94, 157, 177.

In five cases (31, 36, 44, 177, 208) the ball lightning constitutes one of the first discharges. On four occasions it occurs at about the same time as the peak of the thunderstorm activity. 73: during the strongest and nearest discharges; similarly 99, 117, 179, 199. However, relatively often, i.e., in 14 cases, the ball lightning was signified as the last light phenomenon, or it appeared at a time when, in the observer's opinion, the thunderstorm had long ago passed over. 30: the sun was already shining again for some time and only a few, fairly transparent clouds could be seen in the sky; 82: when the thunderstorm had apparently passed over; further, 17, 47, 77, 88, 125, 160, 169, 170, 184, 191, 202, 213.

That the atmosphere is very strongly electrically charged during the occurrence of ball lightnings is also borne out in several cases by the simultaneously or almost simultaneously observed appearance of St. Elmo's fire: 47, 59, 157. It is quite possible that the simultaneous manifestation of St. Elmo's fire occurred more frequently than would seem from these relatively few reports. This phenomenon can easily escape the attention of the observer owing to its weak luminosity during the day.

Little can be said about precipitations during the appearance of ball lightning. Observations regarding the precipitation conditions, if at all made, mostly refer to the entire course of the thunderstorm. This occurs, all told, in 51 cases, which does not exclude the possibility of precipitation in many more instances. The layman associates rain as a matter of course with the thunderstorm, so that he does not consider it necessary to make explicit mention of it. Of the 51 relevant observations 26 refer to the entire course of the thunderstorm, and, in fact, in each case precipitation in the form of rain or snow occurred, with the exception of two cases: 141: a very heavy, dry thunderstorm; 28: overcast sky. — Besides rain, hail occurred five times: 1, 55, 73, 105, 109. In 16 cases the precipitation was described as heavy (downpour, cloud burst, dreadful torrent of rain), twice (151 and 167) only slight rain occurred. In 25 cases details on the precipitatation are given at the time the ball lightning appeared. In three instances it was seen before the onset of precipitation, once after the precipitation ceased, three times when the precipitation started and in the remaining 18 cases during the precipitation — in three cases when the precipitation had reached its peak intensity (36, 73, 180). Twice mention is made of slight precipitation as the ball lightning became visible (43, 123); in all other cases the precipitation was heavy. In 34, 35, 104 c, 105 b snow accompanied the ball lightning phenomenon. In further cases hail occurred, twice after the ball lightning appeared, while in the two other cases before and afterwards. Hail as an accompanying phenomenon of ball lightning thus occurs relatively frequently; however, owing to the limited data we must, of course, excercize great caution in arriving at such conclusions. Brodersen, who investigated the 51 reports of ball lightnings in his compilation of lightning discharges on the basis of the accompanying precipitation,

arrived at a much more reliable result. The question concerning hail was answered in these reports 11 times in the affirmative and 30 times in the negative[1]). The apparent inconsistency is explained when we take into account that in Northern Germany, i.e., also in Schleswig-Holstein, hail is designated as solid sleet particles up to 5 mm in diameter (these occur very frequently during the April sqalls), while according to the definition in Southern and Central Germany hail is understood as the actual hailstones, which hardly occur in the north and which in the south also are much less frequent than the April sleets of the north.

In Brodersen's survey rain accompanied the ball lightning in 47 of the 51 cases — twelve times it was more intense after the lightning than before, three times more intense before than after, in five instances rain started only after the lightning discharge and twice there was no rainfall at all. Thus, there exists a qualitative agreement with the above findings.

We should still mention that in certain instances the precipitation ceased when the ball lightning phenomenon came to an end (77, 105). On the other hand, in 123 the discharge was followed by heavy precipitation: first there were some scattered raindrops; after the ball lightning heavy rainfall followed; in 46 and 184: the discharge was followed by a downpour accompanied by hail and snow.

Incidence of ball lightnings

In general, only one ball lightning appears. However, there are also a group of cases (24 in the present collection), whose number could be increased had we decided to include certain older and more recent reports, whereby two or more balls were seen. Two isolated balls were observed in six cases (11, 17, 96, 104 a, 128, 184); three isolated balls likewise in six cases (18, 38, 54, 81, 91, 95 d). In the remaining cases the number of balls is even greater. 36: 25—30 in half an hour; 41: the phenomenon repeated itself on the average three to four times in half an hour; 59: during a powerful thunderstorm a large number of balls were seen; 45: during the hurricane in Barbados fiery meteors fell from the sky; 103: ball lightnings were seen everywhere during the hurricane; 95: among the electrical phenomena, which accompanied the funnel-shaped cloud, the fireballs were most frequently and definitely identified. Further examples can be found in 55, 69, 102, 139, 199. To these we can add a series of cases from the literature not cited here: 7 June 1888, Ilz: uncommonly heavy thunderstorm; toward 8:45 p.m. several magnificent ball lightnings were observed (Mitt. Nat. V. Steiermark 25, 228, 1888). 30 and 31 June 1892, Kleisdorf: a few lightning flashes were observed which disintegrated into innumerable balls (ibid 29, 428). 25 August 1890, St. Andrä: during the heavy thunderstorm on this day several ball lightnings were seen by Prof. Jäger as well as by other persons (ibid 27, 424; further 28, 349, 29, 427 and 429).

Thus, in the reports from the mountainous regions of Steiermark and Kärnten, where thunderstorms (in many cases very heavy thunderstorms) occur very frequently, mention is made of a large number of ball lightnings. In those reports dealing with the appearance of several balls the thunderstorm is described as being of extraordinary vehemence (17). This further

[1]) Brodersen. op. cit., p. 246.

supports the assumption that ball lightnings most frequently occur as a result of heavy thunderstorms. Again, the appearance of an uncommon number of such discharges seems to be connected with certain hurricanes, such as that observed in Barbados (45), the hurricane in 103 and the tornado in 95. This, of course, does not imply that the ball lightnings belong to the characteristic phenomena of such storms; we can merely infer from the narrow relationship between this phenomenon and thunderstorms that in general ball lightnings occur during the heaviest thunderstorms.

In certain cases the ball lightnings occur in the form of double or higher-multiplicity balls, which at times seem to be connected to one another by a fine luminous strip. 173: two head-sized balls rolled up along both sides of the drainpipe at a distance of about $1\frac{1}{2}$ m apart; 181: a luminous, spherical mass was seen; about 1.5 m below this mass there was a second, smaller ball, which was connected to the upper ball by a fine strip similar to a string of beads. A similar observation was made in the following cases, 73: there suddenly appeared between the branches of a clump of trees a bright purple red, pear-shaped luminous form with several small spherically shaped forms thereabove at a height of about 4—5 m above the ground; 62: closely behind the large ball there followed a series of 4—5 smaller balls the size of billiard balls. Here, we are probably dealing with a transitional form to the likewise rarely occurring beaded lightning, whereby the entire lightning path consists of a series of luminous points, which give the lightning the appearance of a string of beads[1]).

The number of ball lightnings is, of course, very small in comparison to the ordinary forms of lightning. Very few people have witnessed such a phenomenon. However, judging by the relatively large number of reports in the literature, they do not seem to occur as seldom as hitherto maintained. It is, of course, impossible to make any quantitative assessment. Nevertheless, some idea can be obtained in the following way. In his collection of 1747 reports of lightning discharges in Schleswig-Holstein over the period from 1884 to 1899, Brodersen refers to 51 cases of ball lightning (a large number considering the short period) which he regards as true manifestations of this phenomenon. The present author has his doubts in this respect and for this reason has selected only a few reports from the above compilation, the more so, since many reports merely contain statements of the type: lightning in the form of a ball (2028), the lightning was to have appeared in the form of a fireball (1782, 2027 and others), alleged fireball (1993), etc. However, if we assume Brodersen's data to be correct, then, accordingly, 3% of all the lightning discharges which struck buildings (i.e., not all the lightnings) must have been ball lightnings. Another assessment is obtained on the basis of a random count carried out by Häpke[2]). Among more than 400 noiseless summer lightnings he saw one — i.e., 0.25% — ball-shaped lightning, which apparently fell straight down and fairly slowly toward the earth. Accordingly, we can estimate the number of ball lightnings at 2—3 per thousand lightning discharges.

As regards the local distribution of ball lightnings, we see that these are observed in open terrain as well as in cities, whereby a larger number

[1]) A photograph of a beaded lightning, reported by Schmauss, can be found in Met. Zs., 29. 83. 1910.
[2]) Häpke. Beiträge zur Physiographie der Gewitter (Contributions to the Physiography of Thunderstorms), p. 16. — Bremen. 1881.

of cases occur in the open country. In the present collection only ten observations of ball lightning on the sea have been included. In the literature, however, there are further reports. Ten cases from earlier times without specification of the dates can be found in the surveys of Sestier and Arago; however, apart from the fact that these reports obviously do not constitute original sources, they contain in most cases the mere statement that a ball lightning had struck, and for this reason have not been included in the present collection. Nevertheless, it seems that the occurrence of fireballs on the sea is not so rare. This is borne out by the fact that in literary works on life at sea mention of ball lightning is sometimes made[1]).

The material compiled in the present collection does not suffice for a study of the problem of a numerical representation of the geographical distribution of ball lightnings. A survey of the observation sites does, of course, point to certain regions of maximum incidence, for example, Paris and surrounding areas, Schleswig-Holstein, the Riesengebirge (Silesia), the Steiermark Alps. However, this can be partly ascribed to the circumstance that more comprehensive compilations of lightning discharges have been made in these regions which, consequently, also point to a correspondingly high incidence of ball lightning. This is certainly true in the case of Paris, where the Académie des Sciences, which has published on many occasions reports of ball lightnings in the journal Comptes Rendus, heightened the interest in publishing such reports. The same applies to Schleswig-Holstein, for which we have the above-cited compilations of Weber and Brodersen. Perhaps the high incidence of ball lightning in the Steiermark Alps and the Riesengebirge should be considered as reliable, since thunderstorms occur very frequently in these regions and since there is as yet no basis for a distribution of ball lightnings other than according to thunderstorm incidence.

Annual trend of ball lightning incidence

The absolute as well as the relative incidence of ball lightning in the course of a year as compared to the relative incidence of thunderstorms is shown in the following table, in which only ball lightnings observed in Central Europe were counted (see also the graphical representation below).

The figure clearly indicates close agreement between the annual trends of both phenomena; however, the relative incidence of ball lightning is lower in May and June and higher from December to March than for thunderstorms. Combining the four months May to August, in which the thunderstorm incidence is highest, these comprise 81% of all the thunderstorms, as compared to only 73.1% of all ball lightnings. Accordingly, winter thunderstorms produce a higher incidence of ball lightning than spring and summer thunderstorms.

[1]) Thus, for example, in Gorch Fock's book "Seefahrt ist Not" ("Seafaring is Dire Necessity") a fisherman's son exclaims: the lightning looked like the sun; I thought that it was a ball lightning. And in a sketch in Universum 34, 551, 1917, "Eine Nacht an der äussersten Seefront" ("One Night Out on the High Sea") we read: A ball lightning, which passed at relatively low speed like a ghost over the ship, blinded the eyes and burst nearby with a dreadful bang.

Central Europe	Dec.	Jan.	Febr.	March	April	May	June	July
Absolute } incidence among a	7	1	4	3	9	15	30	34
Relative } total of 145 balls	4.8	0.7*	2.7	2.1	6.2	10.4	20.7	22.8
Relative thunderstorm incidence[1])	0.1	0.0*	0.1	1.2	6.0	16.1	23.7	21.7

Central Europe	Aug.	Sept.	Oct.	Nov.	Winter	Spring	Summer	Autumn
Absolute } incidence among a	27	11	3	1	12	27	91	15
Relative } total of 145 balls	18.6	7.6	2.7	0.7	8.3	18.6	62.6	10.5
Relative thunderstorm incidence	19.5	7.7	2.9	1.0	0.2	23.3	64.9	11.6

[1]) V. Hann. Lehrbuch der Meteorologie (Textbook of Meteorology), 676. 1914.

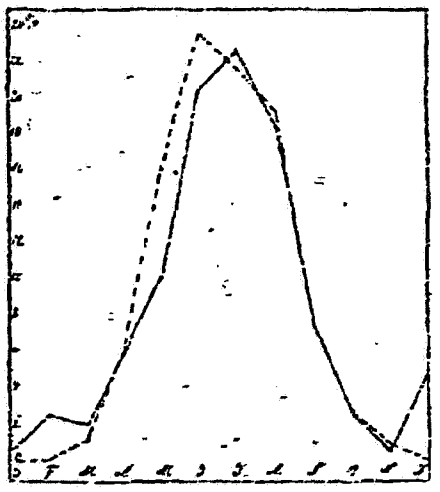

FIGURE 1. Annual trend of ball lightning incidence and thunderstorm incidence (——) in Central Europe.

Diurnal trend of ball lightning incidence

Also the diurnal trend, which was plotted on the basis of 108 reports from Central Europe, indicates, as expected, general agreement with the diurnal trend of the thunderstorm incidence.

Central Europe	Midn. – 2 a.m.	2 – 4	4 – 6	6 – 8	8 – 10	10 – Noon	Noon – 2 p.m.	2 – 4	4 – 6	6 – 8	8 – 10	10 – Midn.
108 ball lightnings	1.9	3.7	1.9	1.8	0.9*	2.8	6.5	13.9	22.2	21.3	12.0	11.1
Thunderstorms[1])	2.9	2.5	2.1	1.9*	2.5	7.1	15.3	21.0	19.3	13.0	8.5	3.9

[1]) Wegener, A. Wind- und Wasserhosen in Europa (Wind- and Waterspouts in Europe), p. 91. — Braunschweig. 1917, after v. Hann, Lehrbuch der Meteorologie (Textbook of Meteorology), p. 681.

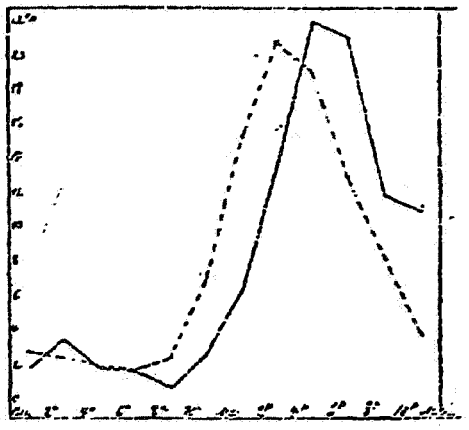

FIGURE 2. Diurnal trend of ball lightning incidence and thunderstorm incidence (———) in Central Europe.

The significance of the values in the table becomes clearer in the above figure. It can be readily seen that ball lightnings occur at lower incidence during morning thunderstorms (midnight — noon) than during afternoon thunderstorms (noon — midnight). This seems to concur with the previously made observation that ball lightnings occur particularly often toward the end or during the final stage of the thunderstorm, which, of course, takes place more frequently during the afternoon than in the morning hours.

104

DESCRIPTIVE FEATURES

Impression on the observer

The ball lightning — or, more precisely, the lightning ball — by no means makes in all cases a dangerous impression on the observer, even when this phenomenon occurs in a room. 27: The phenomenon made an uncommonly harmless impression; 14: it offered such a beautiful sight that at no time the thought of danger or fear crossed my mind; I could only exclaim: Oh, how beautiful! Oh, how beautiful!; 54: one observer, an elderly man, said that he had never seen anything comparable to it in his whole life; he was happy to have witnessed it before his death. Similarly, astonishment without fear is encountered in 12, 16, 41, 117, 158, 209. However, the appearance of the ball has also fairly frequently had a paralyzing effect on the observer; the fright was not so much caused by the outward appearance as rather by the suddenness of the phenomenon along with the accompanying effects (lightning, thunder). 207: the girl dropped to her knees the moment she saw the ball move in her direction; 163: a female day-laborer, who was petrified by fear, saw the ball come her way; 43: without suspecting anything, we sat down at the table, when we were suddenly almost paralyzed by fright owing to the presence of a fireball; 30: Anyone can imagine how startled we must have been. My eyes were fixed upon the frightful intruder; 190: the phenomenon was actually pretty, but I was so possessed by fear that I abruptly stepped back; etc.

Shape

The shape of the ball lightning was indicated as that of a ball in 178 cases, usually with the adjunct "fire, fiery, or spherical luminous mass," etc. That these phenomena in most cases do not involve massive but rather hollow spheres is borne out, besides other parallels (for example, a balloon) primarily by the frequently made comparison with a soap bubble. 77: one of the two observers strikingly compared the ball to a soap bubble emitting an intense yellow light; 52: the ball floated like a soap bubble for a few moments over the lawn; 41: the balls had the appearance of huge soap bubbles and seemed to possess their lightness; 208: suddenly, driven by a gust of wind, a fireball intruded into the room. The fireball, which swayed slightly and seemed to float in the air, circled around the room like a soap bubble, without touching any object. Entrained by an air current, it went out through the window again. Also report No. 30: a round, yellowish, transparent ball 20 cm in diameter — offers further support for this assumption.

However, there also occur marked deviations from the spherical shape. In three cases the ball lightning was described as egg-shaped (44, 73, 137), and in five other cases as oval-shaped (6, 53 (golden egg), 150 (oblong dove egg), 175 (oval fireball), 106 (wide at the bottom, point at the top)). In one case (177) the ball lightning allegedly looked like a tongue of fire; also mentioned are the shape of a balloon (14, 106), lamp shade (45), heart (93), almond (152), star (99), incandescent lamp (151), amphora (109), curved cucumber (156); in 210 it is compared to a young, average-sized cat, which had tucked itself into a ball and rolled about without using its paws for support. Likewise, the ball lightning is once described as a round body (179), as a round flame (65), rod-like (88), pillar-shaped (39), zigzag flamelets (191). There still remain all those cases in which no clearly marked shape is mentioned, such as: flames with poorly defined contours, balls of flames, clumps of fire (55 (2—6), 69, 38, 105, 31 (3)). At any rate, there is an overwhelming predominance of the spherical shape.

Among the deviating shapes, the oval-shaped form, which we can take to include also the pear-shaped form, occurs, relatively speaking, the most often, whereby it is found that when this shape is described the longer axis is usually vertical: only in 196 does the oval-shaped form have a horizontal major axis.

Contour

In several cases we find that the contour of the luminous mass was not sharply defined. 10: the contour of the ball was not sharply defined as in the case of the moon; it seemed much more as if it were enveloped in a luminous atmosphere, whose dimensions could not be reliably specified; 196: ball with a blurred contour; 197: the ball did not possess a sharply defined contour, but rather exhibited protrusions to all sides during its motion; 211: the contour was somewhat irregular; details of its shape could not be distinguished owing to the high intensity of the light. Further examples can be found in 31, 38, 39, 55 d, 68, 127.

On the other hand, in certain cases the ball is described as having a sharply outlined contour (113 and 139); 158: the ball was apparently cir-

cular in shape and its contour was sharply defined; 173: the balls had sharply outlined contours. A comparison shows that the last four cases were all instances in which the phenomenon was observed at a remote distance: in 113 from a distance of 100 m, in 173 — 200 m, in 139 — 1,500 m; in 158 the ball lightning moved from one cloud to another. However, in the examples of the first group there is only one ball lightning (197) which was seen from a distance of 300 m; the remaining ball lightning phenomena took place partly in the direct vicinity of the observer — 1 m in 39, 55 d, 68 — and partly at a distance of a few meters; in 196 no mention of the distance is made. It thus seems that greater reliability should be attached to descriptions involving blurred contours.

The lightning ball in 10 seems to have possessed an aureole. A similar shape is also encountered in the following descriptions. 68: the ball was bright red in color and possessed a bluish fringe the width of a hand; 164: very intense and wide halos surrounded the contour of the ball; 199: it created the impression of a disk, whose intensity decreased slowly toward the outer rim as it descended earthward; 132: in the office it was surrounded by a mist envelope, but no longer in the pharmacy; 25: inside the ball there were several light spots, like musket balls on a disk, whereby the whole was engulfed in a sea of fire; 152: a fairly flat, fiery body having the shape of an almond or a heart, dark red in the center and brighter at the periphery; 187: the ball was 10 — 12 cm in diamter; it was surrounded by a 3-cm-wide circular ring of different color; 30: a round, yellowish, transparent ball of about 20 cm diameter; at its center there was a blue flame, which was pear-shaped with the tapered portion slanted downward and had a length of 4 cm.

Accordingly, the aureole seems in most cases to possess a color differing from that of the center of the luminous mass. Perhaps it occurs more frequently than we would be led to believe on the basis of these few exceptional cases, and is the underlying cause that the periphery of the lightning ball is often described as blurred; perhaps it is this very aureole that effects the deviation from the spherical shape. This would explain the almost spherical shape of the (dark red) center and the elongated luminous envelope.

In several cases reference is also made to protrusions or appendages: 17: at the upper portion of the ball there was a type of red flame, comparable to the fuse of a bomb; 162: the ball, which was about $1\frac{1}{2}°$ in diameter, possessed a narrow, pear-shaped appendage, which extended over a length of $1\frac{1}{2}°$; 73: pear-shaped with several smaller spherically shaped forms thereabove; 165: the shape was most peculiar; the presence of a small indentation on the left edge, from which a small shadow extended over the surface, indicated that the lightning was whirl-shaped; 214: the blue sphere possessed two yellow protrusions emanating from the upper quadrants. In addition to the above examples we can cite a case (Comptes Rendus 34, 896, 1852) in which the shape of the ball lightning is compared to that of a tadpole.

These indentations and protrusions, which as a rule seem to be vertically oriented, again remind one of the oval-shaped form. In other accounts we encounter light bundles or rays emanating from the surface. 129: from two sides of the ball emanated two identical firebundles approximately 50 cm in length; 206: like an electrical sun, from which a bundle of rays streaked up into the air; 190: the ball hurled forth sparks. Apart from further examples, this phenomenon is especially manifested in the sole existing sketch of a ball lightning (31) which was described as follows: streaks,

whose length was greater than the diameter of the ball itself, shot out of the latter toward the right and downward; shorter streaks emanated from the left side of the ball. According to another account, rays emanated from the ball like a catherine wheel; the observer saw this happen three times.

Alterations in shape

In a few cases we also encounter alterations in the shape of the phenomenon. 210: when the ball had reached a height of about 1 m above the floor, it became somewhat elongated and made its way along a slanted path toward a hole covered with paper in the chimney; 211: the contour seemed to alter its shape; 109: a large oblong sphere having the shape of an amphora contracted to an almost spherical form; 37: the fiery snake changed its shape into a ball $^1/_3$ m in diameter; 11: a ball 20 cm in diameter fell onto the pavement and then drew itself out into a luminous rod; 9 (a somewhat mysterious account): a ball 18 cm in diameter gradually turned into a thin, slightly luminous strap; 45: as the ball accelerated toward the earth it became oblong in shape; 196: the initial ball with blurred contours turned into an oval with the major axis directed horizontally.

Size

The size of the lightning balls varies over a very wide range – from the size of a hazelnut, or even a pea, we find balls up to a diameter of allegedly 27 m, such as Less (see p. 109) had calculated. Neglecting at this stage the actual numerical values stated, we find that a number of objects have been employed as a measure for specifying the size of the ball lightnings and which, on the other hand, owing to their selection contribute to the description of the appearance of these phenomena. The object most frequently chosen for comparison is the moon, which is referred to in 17 cases; the skittle ball is mentioned 16 times (in another case the size is compared to twice the size of a skittle ball). In two instances the ball lightning is compared to the sun, and likewise in two cases to a bomb. In 14 cases its size is estimated as that of a man's head, and in one instance as three times this size. The size of a child's head is mentioned in two cases, the size of a fist in six instances, while in one account we encounter a reference to twice the size of a fist; the size of the ball lightning was four times compared to that of a hen's egg and once to that of a goose egg and a dove's egg, respectively. In four accounts the comparison used was an apple, in six cases a billiard ball, in five cases an orange, and in two instances a hazelnut. A small child's ball, balloon, cannon ball, cricket ball, hat, plate, bottom of a water jug, opening in a sack of grain, twice the width of a drainpipe and lamp shade all occur once as objects for comparison. In addition to this we encounter less definite or altogether unspecific adjectives, such as enormous, fourfold, mighty, twice, extensive, once, large, eightfold, small. In many cases no reference is made to the size at all.

Despite this multiplicity certain definite orders of size can be nevertheless recognized in the above list. Skittle ball, man's head, cannon ball, hat, plate, balloon, lampshade, etc., are more or less comparable to one

another as regards their diameter, so that we can estimate the diameter of the ball lightnings compared to the above objects as about 20 cm. Also, when the layman observer compares the size of the lightning ball to that of the sun or the moon, then this estimate is in good agreement with the above order of magnitude. Likewise, fist, orange, cricket ball, goose egg, large billiard ball, child's ball have similar dimensions, namely about 8—10 cm. Thus, in the above list balls having a size comparable to that of a hazelnut, i.e., 1—2 cm in diameter, form the lower limit of the size range. The distances at which these ball lightnings were observed could not, of course, be taken into account; however, in many cases the ball lightning was seen in the immediate vicinity of the observer, for example, 36: average-sized skittle ball, observed from a distance of a few paces; 27: head-sized ball from several meters; 210: head-sized ball, observed in a room.

These inferences will be further verified by a study of the numerical values given. Here, as well, the values of the diameter vary between 2—3 cm (the smallest) and 20.3—27 (the largest), i.e., the size range is
09 so wide that it is impossible to specify some mean value. The largest size (27 m) was calculated by Less (139) from the apparent size (equal to $1\frac{1}{2}$—2 times the size of the moon) and the presumed height of the thunderclouds based on the meteorological parameters. How careful one must be in regard to such calculations is particularly evident in the studies of Witte[1]) on the field of vision in which the visual size of the moon is comprehensively treated. In 199 the diameter of the ball lightning is indicated as three times the width of the preceding ordinary lightning discharge; in 41 the size is stated as 1° at a distance of 1 km. It is hardly erroneous to assume that in all these estimates made at great distances the apparent diameter was strongly overestimated owing to the light intensity. Data on fireballs observed near the ground which in part refer to observations made in closed spaces and in part in the immediate vicinity of the observer point to significantly smaller values. Seven balls fall in the size range up to 10 cm, thirteen in the range 10—20 cm, four in the range 30—40 cm, three in the range 40—50 cm, one in the range 50—60 cm, two in the range of about 1 m. We thus recognize a prevalence of the size range of 20 cm, a result which is in good agreement with the above deliberations.

Nevertheless, these results are subject to a certain degree of uncertainty, since the distances at which the phenomena were observed exhibit a wide range of fluctuation. However, an essentially similar picture is obtained, when those cases corresponding to large and small distances, respectively, are classified according to groups. Taking into account only those ball lightnings, which were observed in closed spaces or in the immediate vicinity of the observer — i.e., up to 6 cm — we obtain the following result: 1—10 cm, six; 10—20 cm, eleven; 20—30 cm, two; 30—40 cm, one; 40—50 cm, none; 50 cm or more, two. The size of an apple (orange, etc.) is mentioned in 13 cases, that of a skittle ball in 14 cases. Among the balls observed in rooms we thus see that there is an increasing trend toward diameters of the order of 10 cm compared to those of the order of 20 cm, while here, as well, the latter is still the prevailing size range. The remaining data on the distance are in part so unspecific and part differ over such a wide range that a further classification would be of no significance.

[1]) Phys. Zs. 19. 142. 1918 and 20. 61 ff. 1919.

Numerical values also exist for lightnings, whose shape differs strongly from that of a sphere. 88: rod-shaped body, 15 inches in length, 5 inches in diameter; 152: almond without a kernel, 32 cm long, 22 cm wide, 1 cm thick; 175: oval fireball, 50 cm long, 25 cm wide; 177: fiery tongue, 40 cm long, 10 cm wide, 1 cm high; 44: pear-shaped, 4—5 inches in diameter, 6—8 inches in length; 187: spherical core of 10—12 cm diameter, surrounded by a circular strip of 3 cm width; 51: egg, 4 ft long, 50 cm in diameter; 39: pillars of 2 m length and 3—15 cm width. With the exception of the last two cases, here, as well, the size differs only slightly from that of the distinctly ball-shaped lightning (this particularly applies to 175, 187, 88, 44). Owing to the excessively large numbers associated with the lightning in 51 and the dimensions and shape of the pillars in 39, these cases can by no means be classified in the framework of the ordinary types of ball lightnings. Only the cases in 51 and 152 were seen in the immediate vicinity of the observer and in a room, respectively; in the other cases there is a complete lack of direct data on the distance and they cannot be reliably estimated on the basis of the description of the observer site.

Just like variations in shape we also encounter variations in volume. 35: the volume of the ball grew and finally reached a diameter of 30 cm; 68: when I first noticed the ball, it was the size of a child's head; however, as it passed by it had a diameter of $\frac{1}{2}$ m; 77: the ball first had the size of a soap bubble, then expanded uniformly in all directions and reached a size of two widths of a full moon; 96: the ball which appeared in the almost black cloud layer rapidly became brightly luminous and also somewhat larger. Further examples are: the flame, which hovered 3 feet above the floor in the church on July 2, 1750, then ascended to a height of 12—15 feet, thereby increasing in size[1]). A traveler saw in 1716 in the mountains a number of ball-shaped bodies of differing volume fluttering around in the clouds; he observed how one of these grew appreciably in size in a very short time[2]).

Examples in which a reduction in size occurs are given in the following reports. 101: in the middle of the street there suddenly appeared a fireball the size of a skittle ball, which rapidly contracted; 55_8: the flame ball was very large in the beginning, but as it reached the center of the kitchen its size was reduced to that of an orange or even an egg; 9: the fireball first hollowed out a groove of 18 cm in diameter, then jumped down again and ripped at a distance of 3 m a new groove of only 9 cm in diameter; along its subsequent path its volume decreased and finally it was no larger than a thin, slightly luminous strip. In part these variations in volume are attributed to changes in the angle of view; this is certainly the case, for example, in 68. Nevertheless, it is, of course, possible that these variations are in fact real.

111 Rotation

In a series of cases it can be inferred that the lightning balls rotate about an axis, or a rolling movement was directly observed. 209: it looked as if the fireballs were rotating with great speed; 89: the luminous ball was rotating: 120: the ball rotated about a horizontal axis, which was transverse

[1]) Arago. 4. 40.
[2]) Plante. op. cit., p. 93.

to the direction of motion, so that the rotation was from up downwards on the side facing the observer; 135: the ball rolled along the floor; 165: owing to the presence of a small indentation on the left edge from which a short shadow extended over the surface, it can be concluded that the lightning was whirl-shaped. Further examples can be found in 9, 14, 67, 110, 161, 167, 189, 201, 205, 210. The fairly large number of such observations would lead one to presume that this involves a frequent, if not general, property of lightning balls. The whirling movement of the ball lightnings is reminiscent to a certain extent of the rotation of the humming and hissing dc carbon arc, whose current intensity is subjected to periodic fluctuations.

Color

Classifying the ball lightnings according to their colors, the following table is obtained; the main colors distinguished are white, bluish white, blue, green yellow, red-yellow, red and a mixture of colors.

Colors	White	Bluish white	Blue	Green	Yellow	Red-yellow	Red	Mixture	Total
Absolute frequency	14	4	11	2	15	14	46	2	108
Relative frequency	12.9	3.7	10.2	1.9	13.9	12.9	42.6	[illegible]	

Of course, the color tints are not homogeneous within the individual groups, but come in various shades; in white, for example, from glowing white to slightly pinkish white; in red — from dark red via bright red, pale red to rose-colored red, and bluish red; in yellow — from gold yellow to nearly white yellow.

If, as is usually done in the case of meteors, we group together the yellow, red-yellow and red ball lightnings, on the one hand, and the bluish white, blue and green ones, on the other, then the first group comprises 69.4% of the cases, while the second only 15.8%; consequently, there is a clear predominance of the red-yellow group, which comprises nearly $^3/_4$ of all the cases. However, in the above table the specifically red color is also the predominating one (42.6%, i.e., in $^2/_5$ of all cases). This constitutes overwhelming evidence in favor of the predominance of the red color. Moreover, the cases listed under red-yellow contain intense red components, and, further, in the many cases in which the color is not specifically indicated, usually the word "fire-" or "fiery" ball refers directly or indirectly to the reddish color of fire.

Among the nuances of red the most prevalent, disregarding the ten cases in which neutral red occurred, is dark, deep or blood red (13 instances, or with crimson and deep purple red — 15 instances); fire red occurred four times, like the setting sun once, red like the moon colored by mist once, reddish nine times, pale red once; the remaining instances are color mixtures with predominant red components. The designation "yellow" balls also occurs relatively frequently, which, however, is probably associated with the fact that when we look from lamp light to red light, the latter seems light yellow, so that in reality we can regard the number of red ball lightnings as being even greater.

Green coloring is reported very rarely; I could find only two cases in which reference to this color was made. On the other hand, the colors with short wavelengths, the blue colors, which seem to go over into all shades of white, are encountered more often. In addition, there are ball lightnings, whereby no explicit or predominant color is mentioned. The allegedly rainbow-colored balls are reported in: 104 c: spherical masses of fire glittering in the most varied colors; 189: lower third dark gray, the upper two-thirds enveloped in the more lively, swirling colors of the rainbow with a predominance of green, while the point was bathed in an orange color. Also in the case of other balls which have already been listed in other columns in the table owing to their predominant coloring, mention is made of other colors. 109: green, at the upper end streaked in red and yellow; 39: yellow, light pink, lower portion of the posts yellow, green, blue; 10: reddish yellow with a few spots of deeper red. These luminous phenomena, which are again reminiscent of soap bubbles, probably led Poey (see below) to the conclusion that the colors of the ball lightning were due to interference phenomena occurring upon the reflection of sunlight from the thin envelope enclosing the fiery mass.

Even black balls have been reported. Thus, on September 9, 1877, a black ball was seen in the middle of a kitchen in a house at Castelgandolfo[1]); it looked as though it consisted of dense smoke, was 25 — 30 cm in diameter and burst, while hurling about flames, in front of a woman without causing her any injury; the ball then retreated via the open door, without causing any further damage. However, the description, which was given by a woman, contained certain contradictions, so that we can ascribe little reliability to the alleged color. For all we know, the ball could have been blackened by chimney soot.

The clear predominance of the red color in ball lightnings suggests a comparison with the likewise observed predominant red color of meteors which is caused by the glowing of the nitrogen in the lower atmospheric layers, the stratosphere. The possibility exists that the red coloration of most ball lightnings is also associated with the same cause. This is borne out by further observations of the occurrence of vapors, about which we will say more below. A decisive verdict, however, can be given only on the basis of spectroscopy.

Nevertheless, changes in the color of ball lightnings also occur, though, as a rule, only as they burst. 41: reddish, at times yellow, white during the burst; 45: when the ball approached the ground, it became dazzling white; 59: at first yellowish, after the explosion reddish and blue; 88: as the ball burst there was a dazzling white light in the middle which became a pink red further out; 180: as it exploded in the originally red ball sprayed rainbow-colored sparks about, while according to another account the sparks were all of the same red color.

Light intensity

The light intensity of the balls differs widely in the various reports; however, all accounts acknowledge that the intensity must be considerable. This is already borne out by the frequently occurring word "fiery"; in other

[1]) Atti della Pontif. Accad. Rom. dei Nuovi Lincei. 66. 63.

cases luminous, shining, intensely luminous or shining, flaming, blinding, etc., are used to describe the degree of brightness. This applies to nearly all the 60 cases, in which mention is made of the brightness. At times we encounter further reference to the light intensity. 43: the ball emitted a bright gleam over the surroundings; 64: the ball illuminated the house and yard in all colors; 68: luminous, emitting an extremely intense light, so that the entire region seemed as if it were electrically illuminated; 83: believing that it was a fire, I turned my head and saw a fireball; 211: owing to the high light intensity details could not be distinguished; 127: the mass had such a lustre that it was impossible to see its periphery sharply.

Somewhat less extreme are the following remarks—154: less dazzling than the immediately preceding lightning; 171: not excessively luminous; 122: bright, but not blinding; 210: it seemed more like it was shining and luminous than hot and fiery; its lustre was by no means blinding. Apart from these rather general descriptions there are isolated instances in which a direct comparison with other light sources is made. 151: light similar to that of an incandescent gas lamp; brighter than a filament lamp.

114 As regards changes in the brightness in the course of the phenomenon, the case in 96 — emitting light in the almost black cloud layer, as if a star was twinkling through; the ball rapidly became brightly luminous — is probably attibutable to the decrease in the distance. In 98 we read: I saw a star with a brightness comparable to that of Sirius; after two minutes of unattenuated light emission it started to fade and disappeared completely one minute later.

Frequently there occurs an increase in brightness before the lightning balls extinguish. 36: as it burst it spread such a dazzling light that I was momentarily blinded; 41: as the balls died out they generated a blinding glare; 117: the ball exploded with the emission of light, likewise 187. Curiously, this intensity rise was observed only (except in 17) in the open, whereas no mention is made of any such increase in brightness in the many instances where ball lightning was observed in a house.

There are only few cases in which differences in brightness at different points of the ball are reported. 199: it looked as if a disk, whose intensity slowly decreased toward the rim, were moving toward the earth; 187: I saw a ball bathed in the most beautiful orange light, which was more lively in the center. Thus in both cases the intensity decreases in the outward direction. Less clear are those cases in which differences in color are described; 152: dark red in the middle, brighter at the periphery; 68: the ball was bright red in color and had a bluish fringe the width of a hand.

Smoke

Occasionally the ball lightnings allegedly leave a trail of or are surrounded by smoke or vapors. The ball in 9 was accompanied by vapor trails; in 12 the ball evolved a dense smoke with a sulfuric odor. In 43 we read: at the same time a dense bluish smoke entered via the door from the fire place inside through which the fireball probably passed. Further information is found in two reports, which were not included in the present collection, since their original source could not be established: two persons, who were staying in a room, suddenly saw a fiery ball the size of a fist appear at the height of their heads and at a distance of about one foot. This ball was

enveloped in black smoke[1]). On the afternoon of May 7, 1889, a man saw in the vicinity of Paris an oval, brightly luminous fireball of 50 cm length in a street. Three times it discharged a small grey smoke cloud with a pungent, suffocating odor which attacked the throat. They were similar to the puffs of smoke coming out of the chimney of a locomotive when it starts to move. The odor was sulfurous or, better, smelled like burnt gunpowder[2]).

The generation of vapors is mentioned in the following cases: 86: the house was filled with an orange gas, which produced a suffocating effect upon exhalation as in the case of burning sulfur. A sample of N_2O which was heavily diluted with air, was placed before the observer. He declared that the gas in his house was bright orange in color and had a similar, though not the same odor. However, when a less-diluted sample of the gas was placed before him, he was completely convinced that the two gases were identical both with regard to color and odor; 73: at the site, where the fire phenomenon had occurred, there formed a whitish mist, which cleared up only after half an hour; 95 c: the balls which intruded via the chimneys and the oven doors in the dwellings left a trail of spiral-shaped streaks; 162: the fireball left behind only a dense, dark blue mist, which remained over the sea during the thunderstorm.

In reports of this kind the possibility of an illusion must be borne in mind. For example, the spiral-shaped streaks in 95 c can be attributed to soot, which was blown out of the chimney after lightning had struck again. However, on the basis of these observations it is quite possible that ball lightnings leave, at least in certain instances, a trail of smoke. The pressumption of the observer who gave the account in 86 that N_2O was involved can by no means be outright denied. The formation of such nitrogen gases would, for example, also clarify the occurrence of the white mist in 73, since the gas particles can act as condensation nuclei and can transform the air saturated by the heavy hail shower into a particularly dense and persistent mist. A similar case is encountered in 162, where the ball appeared over a body of water. That the color of the vapor differs according to the various accounts can be explained by the fact that viewed from the side the mist is red brown, while viewed from the top — bluish (phenomena encountered in the study of turbid media). It is precisely the brown mist (probably indicating smoke) which seems to have been observed more frequently.

16 Odor

The generation of gases could also explain the odor perceived in a series of cases during or after the appearance of the ball lightning; conversely, the perception of odor as a result of a ball lightning can be regarded as a confirmation of the assumption that ball lightnings frequently leave behind gaseous formations upon their dissipation.

The odor is usually associated with that of sulfur (12, 19, 20, 34, 37 c, 74, 98, 140, 182). In another report (not included in the present collection)

[1]) Arago. 4. 37.
[2]) Mem. della Pontif. Accad. Rom. dei Nuovi Lincei, 28, Ch. 31. 1909, after Charcot: Leçons de mardi à la Salpétrière, 19e Leçon, Paris. 1889.

of a ball lightning at the Pikes Peak Observatory[1]) an assistant claimed he saw an electrical discharge and that thereupon a fireball, leaving behind a sulfurous odor, passed through the storage room. In other cases, namely those in which the accounts stem from scientifically trained observers, the odor was designated as that created by ozone (44, 95, 168). As proof of the presence of ozone it was alleged in one case that the middle of a yellow damask curtain exhibited bleached spots (95). In one case (13) mention is made of an odor consisting of a mixture of the odor of sulfur and garlic, which was actually reminiscent of ozone; in another instance the odor is associated with nitrous oxide — laughing gas — (86), while elsewhere (43) the odor is compared to that of gunpowder or that produced by a rifle (121).

Thus, the odor specifications encountered here are the same as those known from ordinary lightning discharges.

These 17 comprehensively described cases, in which a sharp odor was detected, are countered by only five cases, in which the absence of odor is expressly mentioned — 29, 61, 132, 192, 211. In the last case the following unspecific statement is made: "the ball did not leave any ozone-like odor," so that the possibility of some other odor cannot be excluded here.

Lapses of memory or illusions also occur. For example, when in one report[2]) we read: after the phenomenon occurred, a spherical blue flame was perceived which originated from a coal bin and made its way through several rooms until it finally disappeared via the chimney, hurling smoked hams onto the street and giving rise to a sulfurous odor lasting for several days, then this is most probably an illusion. An illusion is likewise the probable cause when a person, who was struck by lightning, perceived an unbearable sulfurous odor for eight days in his immediate vicinity[3]). According to another report a ball lightning[4]) imparted a strong odor of burning sulfur to all the water which gushed forth abundantly from a large container.

Traces

Not much can be said about visible marks left by ball lightnings. In most of the cases the ball lightnings disappear without leaving a trace (3, 32, 40, 50, 51, 55_2, 62, 73, 77, 83, 89, 110, 132, 192, 6, 12). In one instance (118) it was added that even after a painstaking search no traces could be found. A similar situation is encountered in 29: immediately after the fireball vanished I ran to the place in question, hoping to find parts of it on the ground, but there was nothing left. Only in two cases a black mark was found on the ceiling, while on the floor, where the ball disappeared, no trace could be found (193 and 211).

Heat effects

The temperature of ball lightnings and, consequently their heat effects are seemingly subject to wide variations. That the temperature is fairly

[1]) Sitzb. Wien. Ak. d. W. IIa, 97, 654, 1888.
[2]) Flammarion, C. Op. cit. p. 90.
[3]) Mem. della Pontif. Accad. Rom. dei Nuovi Lincei, Ch. 32. 1909.
[4]) Ibid 30, 308. 1911.

insignificant is in part borne out by observations of eyewitnesses, who were in the immediate vicinity of the ball or came into contact with it, and in part by the circumstance that fireballs very rarely give rise to heat effects along their path. 210: the ball was shiny and luminous rather than hot and fiery; it emitted no noticeable heat; 132: no heat was perceived; 2: the ball continued along its path without igniting and passed close by the feet of a woman; 138: the ball moved very slowly through the room, whereby it made slight contact with four people; no one was injured; 207: the ball alternately struck the ceiling and the feet of the girl without causing anything more than a slight cramp; 51: I could not detect the slightest trace of fire either at the point where it entered or at the point where it left; some dry moss, which was dislodged from a crack by the ball lightning, showed no signs of burning; 37c: the ball lightning rolled about the threshing-floor, where my uncle was working, and burst into pieces without igniting the hay; 193: the ball slowly slid down along the curtain and did not ignite the latter; the only mark left behind was a dark spot the size of a pfennig on the wood in the ceiling. The last observation repeats itself in 211: when I thoroughly examined the floor, I could not find the slightest sign of burning; however, on the ceiling, there was a black smudge on the white paint. Finally, let us mention a report which is not included in the present collection[1]): in Vincennes, after a lightning discharge, which followed a deafening thunderclap, a ball entered via a door, which stood ajar, into an ammunition factory, rolled amidst 20 workers and 500 loaded shells, and then left via a small gate without causing any explosion.

These reports, however, are contradicted by others, in which mention is made of a perceptible heat of the ball lightnings or even the effects of ignition. 20: I felt a heat sensation on my face similar to that caused when opening an oven door; 60: as the ball lightning drew nearer, the lady felt a hot, fresh breeze on her check, but there were no stinging sparks; as the ball fell a noticeable heat effect was perceived; 58: the ball slipped into the décolletage of the woman... over her entire body only superficial burns at the point where the corsette was tightest were found; 209: the ball burned the grass along its entire path; 126: the straw started to smoulder along the path followed by the ball as it rolled down the roof; 95: the balls set the hay afire; 26: the fireball merely ignited the matches on the mantlepiece; 117: my hair and clothes were singed and smelled of burning; further examples can be found in 3, 19, 34, 55_1, 121, 143, 188.

These alleged heat effects often occur during the explosion of the ball lightning or are observed afterwards and attributed to the explosion. 2: as the ball reached the lower edge of the straw roof, it exploded and disappeared; the shed caught fire; 92: at this moment ray-like lightnings emanated from the fireballs and at the same time set fire to nearly all the surrounding buildings; 118: the ball exploded; the seamstress, who was sitting next to the window, received a burn on the forehead; 178: the ball exploded and melted the electric wires below the bells, which themselves remained undamaged; on the stairs which lead to the choir, it burnt out the small lamps.

It is, of course, possible that part of the heat effects observed during or after the occurrence of ball lightnings should in reality be attributed to other electrical discharges — frequently referred to as ball lightnings — since it

[1]) Flammarion, C. Op. cit. 227.

cannot be reliably established whether the igniting effect was actually observed - discovered only afterwards (see, for example, 178). Also, the other effects described in 134 are completely the same as those of an ordinary lightning. In 20 and 60 we are probably dealing with autosuggestion, since the observer imagined that such a fiery ball must also have been hot. However, in a number of cases the heat effect of ball lightnings cannot be disputed. We are thus left with a contradiction between igniting and cold ball lightnings, and are compelled to draw a distinction between free-floating ball lightnings, whereby heat effects are generally absent, and those which settle on good conductors (or creep along the latter) as well as on the human body, leading to heat sensations or burns.

Physiological effects

That which applies to the heat effects of ball lightnings applies also to their physiological effects upon humans and animals. Here, as well, a superficial scanning of the reports points to a marked contradiction between seemingly harmless ball lightnings, on the one hand, and extremely dangerous ones on the other. Nevertheless, it seems that lightning balls as such are in general fairly harmless. In 31 of the 55 cases it can be established beyond doubt that the ball lightning, despite the fact that it came into very close contact with persons, did not give rise to any effects which correspond to those of ordinary lightnings. A few examples besides several already mentioned in the previous section clearly point to this. 2: the ball passed between the woman's feet without causing her any harm; 12: the ball dropped amidst a child and three women, without causing them any injury; it then passed by the feet of a young man; 177: the ball lightning described circles around the young girl; several persons witnessed the phenomenon, but nobody suffered any bodily harm; 124: the ball flew to within 1 pace past the bath superintendant, who was sitting at a table, and to within 2 paces past the doorkeeper, who was standing in the room; neither was injured; 61: the ball circled around a lamp above the center of the table without causing any harm to any member of the family sitting at the table. Further examples can be found in 30, 40, 72, 104.

On the other hand, we also come across reports which mention shock, stupor and even losses of human and animal life. 25: the child, who touched the ball with his foot, was killed; his playmates were knocked to the ground; 207: the girl, who was hit on the feet by the ball, experienced a slight cramp in her legs; the eyewitnesses suffered no bodily harm; 161: the ball passed five persons at close quarters and knocked one of them over who was subsequently stupefied; 22: four or five children were lying on the ground, one was dead; 143: the ball hit the woman on the head, then fell to the floor in the midst of the gathered company; after the initial excitement had passed it was established that Mrs. K. was dead; some of the people lay unconscious on the floor. Further examples are 26, 57, 83, 109, 111, 121, 159.

If we examine the trustworthiness of both groups of accounts, we see that in the first case the assertions mostly refer to the ball lightning as it moves along its path, while in the second group the subsequently established result is mentioned. In 22, for example, before the ball appeared, pieces fell from the ceiling, so that the former was probably preceded by an ordinary

lightning. Similarly, in 143 mention is made of a powerful thunderclap before the ball appeared on the threshold; the other lightning effects described here are in all respects similar to those of an ordinary lightning; in particular, the marks left by the lightning on the bodies of the stricken, which were allegedly struck only on the head, point to the effect of an ordinary lightning. In 83 the observers claimed to have experienced a heavy shock as the ball lightning exploded; however, since the latter was 80 m away, it seems that such an effect is highly improbable; this probably involved the electrical return stroke occurring after an ordinary lightning hits the ground. In 159 the following is said: the ball approached two young girls and touched the feet of one of them; after it jumped back onto the wall, it broke a rifle; "thereupon" it entered a stable, and killed the cattle, goats and pigs, etc. No one had seen this happen, but the animals were in fact found to be dead and the fireball was subsequently implemented. In the above cases it is therefore possible that the observed effects were actually due to ordinary lightning. In other instances, however, such as in 109, and 207, there is hardly any doubt that it was the ball which caused the paralyzing or cramp-like effects on those parts of the body struck by the lightning. Thus, the general impression is created that free-flying lightning balls are relatively harmless and that their presence constitutes a danger only insofar as there exists the possibility that ordinary lightning discharges occur in its vicinity and that they can manifest their destructive effects. On the other hand, however, here, as in the case of the heat effects, ball lightnings at rest can become dangerous under certain circumstances and cause injury or even death to those who come into contact with them.

Mechanical effects

Among the remaining physical effects of ball lightnings the mechanical effects are so fantastic and bizarre that on the basis of what has so far been said about ball lightnings one would tend at the outset to doubt their capability to produce such effects. This again especially applies to reports originating from France and Italy which describe the ball lightning as a phenomenon endowed with some of the most peculiar forces. One need only read one of the reports translated from the Italian original (for example, 34, 121 or 188) to find that ball lightnings were capable of hurling down the heaviest objects, stones, walls with great force (Planté 102, Galli 30, 268), or even carrying humans and animals through the air (Le Cosmos 1852/53, 139 and 398), without causing them any bodily harm, while at the same time light objects were left standing in their places. In one instance (161) it could knock over a person, while in another (19) it could knock a person down and set him upright again like a spring. Further, the ball lightning bored a hole through thick walls (144), a block of granite (188), as well as doors and window panes (22 and 124), the floor (118), burrowed deep holes in the ground (9), furrowed deep channels in the ground (209), pushed away some tiles on a roof (46), dislodged millboards from chimney openings (210), caused church bells to toll (29), ripped off the cast-iron fixtures on a door, splitting the latter (95d), bored a 3-cm hole through a gourd, while the sack in which it was placed remained undamaged (Le Cosmos 18, 649), drained wine, oil, water (Atti della Pontif Accad. Rom. dei Nuovi Lincei 62, session

of March 21 and 18 April, 1909)[1]). In other instances it ripped a piece off a woman's slipper (58), the bottom off a man's trousers (22), tore a shirt to shreds (3), took some pieces off a wooden tableware cabinet (12), extinguished candles (34), knocked over a filled beer glass, while it left the lamp untouched (137), hurled a morsel of cheese out of the dining room, but did not damage any of the glassware, while all those present were knocked against the backs of their chairs by the force of the explosion (117), slipped a wedding ring off a woman's finger (121), broke a plate, which a sister was holding in her hands, into two pieces (178), took a piece of cake out of a child's hand (183), and other likewise peculiar cases.

2 From the above bizarre examples it can already be seen that in part the effects of ordinary lightnings, whose strangeness is well known, in part other chance phenomena are involved. To effect a distinction between these different effects there exists only one suitable criterion, which consists in determining whether the effects related in the accounts were observed as being the direct result of ball lightning or were established only after the phenomenon was seen. If the reports are examined on the basis of the above criterion, then a whole series of accounts must be a priori excluded. This, of course, does not mean that the observers were guilty of wilful deception; it is quite understandable that laymen, who observe such a rare and peculiar manifestation as a fireball, tend to causally connect all effects, which occur more or less at the time of the phenomenon, with the phenomenon itself. Even when the assertions refer to the balls, caution is called for. A closer examination of these reports already reveals contradictions. It is, of course, beyond the scope of this book to thoroughly criticize all or even a large portion of these reports. To state merely one example (118), we read: the ball bored a hole through the floor and exploded; after the explosion the lightning made its way through the chimney flue. Here, we immediately see that it is impossible that all these events refer to the ball lightning. When a sister drops a plate or a child drops a piece of cake upon seeing a ball lightning, then this need not be attributed to any mechanical effect of the ball lightning. Even when people fall down, there is no reason to right away suspect that this was caused by some mechanical effect of the ball lightning, not even when this happens, for example, in 183, as a result of the so-called explosion of the ball lightning. Reports, such as 46, 124, 159, 168 and others, clearly point to the effects of normal lightning; especially in the last case three developmental phases can be recognized: first an ordinary lightning with normal accompanying phenomena, then the appearance of the lightning ball and after the disappearance of the latter the reoccurrence of the ordinary effects of a normal lightning. Nevertheless, it is very interesting to read the allegation in (142) that the fireball gave rise to a pillar of fire several meters in height as it passed over a river. Unfortunately, the report is so short that it cannot be inferred whether the phenomenon was actually observed that well, or by whom and at what distance.

23 Here, we are probably dealing with a case in which a whirlwind — often described as having a fiery (smoke-like) spherical dust mass at the bottom —

[1]) This last case reported by Galli is reminiscent of a passage in Lucretius. De rerum natura VI, 230–234: Lightning instantaneously melts ore and gold: it causes effects, whereby wine is suddenly vaporized, but the container is left intact, while its heat causes everything in the surroundings to expand, cracking the earthenware container, and entering into the latter, rapidly disperses the basic constituents of the wine.

was mistaken for a ball lightning. It is also peculiar that in three cases it is alleged that the fireball had made holes or furrows in the ground.

Thus, in reality, the mechanical effects, which on first sight are marked by their promiscuousness, hardly withstand the test, so that in analogy with the few physical effects so far found we can assume that in this respect the ball lightnings are relatively harmless. This is further borne out by the fact that in many reports there is not one instance in which something is said about those effects which would definitely have been noticed by the observers, and, moreover, in a series of cases it is explicitly asserted that the ball lightning left intact objects standing along its path, made no holes, left behind no marks (for example, 2, 6, 40, 192 and others).

Magnetic and electric effects

Very little can be said about magnetic and electric effects. Here, as well, several effects are obviously attributable to simultaneous discharges of normal lightning. 192: the electric lamps went out, the bell rang incessantly; 117: the numbers of the dial fell off; 198: at the same time as the explosion all fuses and lamp-bulbs were blown. On the other hand, however, other reports would seem to indicate that it is possible for a lightning ball to close a circuit, also when the electric wire is disconnected at some point. 177: the ball caused the metal filaments of an electric lamp to glow; after an intense lighting up, whereby the flame shot out of the bulb, it suddenly went out. In another house the bulb was likewise actuated, remained lit, and went out only after it was switched off. 185: the ball turned on three electric lights, one of which had burnt out a long time before. 153: the ball moved toward a small telephone, which thereupon started to ring. The behavior of ball lightnings with regard to metals is discussed at a later stage.

Noise

Whereas there exist wide differences in the reports as regards the appearance and effects of ball lightnings, there is noteworthy agreement as to the noise which, apart from the usually simultaneouly occurring thunder, accompanies the ball lightnings. Frequently this noise is compared to the hissing sound of a rocket or of a shell whizzing by. 52: the fireball left the impression of a glowing, hissing ball, 63: a gardener, who was standing in an arbor about 120—130 m behind the high school, exclaimed: "the fireball came with a hissing noise from the roof of the high school and burst above the trees"; at the same time a peculiar noise was heard by the teacher and students of a class in the school in question. On the other hand, a young lady, who was sitting next to a window in a house about 50—60 m away, heard no noise. 56: the ball dissipated with a hissing noise; 194: suddenly a hissing sound like that of a heavy shell was heard; at the same time a fireball was seen moving earthward with moderate speed from the cloud; 190: the ball, which was about 2—3 m away from me, made a noise similar to that of a hissing rocket; 153: suddenly the female cook, who was busy in the back of the kitchen, heard a faint sound in the vestibule. She looked up and saw a mysterious light ... The stablehand, who was

standing in the vestibule, also heard the hissing noise, and it seemed to him as if it were moving away and down the stairs; however, he saw nothing. 5: the observer saw from his room how a fireball ascended up into the clouds with a hissing noise similar to that made by rockets in firework displays. 146: the ball lightning moved with a hissing noise at low altitude through the air. Repeated reference to crackling noises is also made. 29: as the ball struck the wet pavement it burst with a crackling noise into pieces; 35: on the fresh cover of snow on the pavement there appeared a small luminous ball, which grew in size with a crackling sound. 103: the country dwellers speak of fireballs, which move through the air with a crackling noise. 121: those present in the room noticed that the ball made a noise somewhat like crackling. 140: the ball rolled down a side-street with a loud crackling noise. Further, we encounter the following descriptions. 87: roaring; 169: rattling; 203: rumbling; 54: the ball disappeared with a faint roar; 62: a fireball flew over the telegraph wires with a faint noise like that produced by a flag flapping in the wind; 132: the noise in the pharmacy was similar to that produced when a glass chimney bursts; 152: the luminous body was accompanied by a faint buzzing noise similar to that made by the wings of a large beetle; 165: especially during the appearance and disappearance of the phenomenon the faint noise of rapid discharges is perceived. At times only mere mention of a noise is made (82, 193, and others). In the French reports we frequently encounter the onomatopoeic words "bruissement," "sifflement," which characterize the noise made by ball lightning. Only one report (137) mentions that no sound was perceived while the ball passed through the room.

The explanation of this noise, which can be regarded as an established fact on the basis of the various accounts which are concurrent in this respect, in analogy to the whizzing of a bullet passing overhead is improbable, since, as will be later pointed out, the ball lightnings in general travel at relatively low speeds and have a low density. Fluctuations within the ball are likewise excluded as a possible cause. Perhaps the hissing is in no way connected with the actual ball, but associated with the general electrical state of the atmosphere. This sound could presumably be the same as the hissing and crackling which accompanies St. Elmo's fire and which is similar to the sound produced when a Leyden jar is charged so heavily that the electricity rapidly flows into the surrounding air (compare 156). In one instance[1]) the following is said with regard to the hissing sound during St. Elmo's fire: "the St. Elmo's fire was accompanied by a faint hissing about as loud as when one pronounces the letter s in words during normal speech. Intermittently a lightning streak was observed; then the St. Elmo's fire went out temporarily while the hissing ceased, but only to flare up again after several seconds." The hissing also occurs when no visible light phenomenon is observed. Watson and his colleagues ran into a thunderstorm during an attempt to climb the Jungfrau. After a dreadful thunderclap he heard a whistling sound (sifflement), which emanated from his mountaineer's stick and was similar to the noise produced when steam rushes out of a kettle with boiling water. The sticks and pickaxes of the others produced the same sound ... Also the falling snow emitted a hissing sound like that produced during a hail storm; the same applied to the fingers when held up high in the air. After a later lightning discharge all the sounds ceased

[1]) Gockel, Das Gewitter, p. 89. After Mitt. Ges. Winterthur 1897/98, Issue 1, 23.

only to start immediately again[1]). In his memoirs[2]) W. v. Siemens reports a similar experience on the top of a pyramid. As soon as he held his fingers above his head a shrill, singing sound was produced. That an electrical phenomenon was involved was borne out by the fact that he and the other members of the party experienced a light electrical shock when they attempted to drink from a wine bottle. This bottle, which was wrapped in paper and had a metal cap, was transformed into a heavily charged Leyden jar as soon as it was held above the head with the result that loud crackling sparks of 1 cm length emanated from the bottle.

There thus exists a definite correlation between the noises produced in both phenomena. However, judging by the distance involved, the sound generated by ball lightning is apparently louder than that occurring during St. Elmo's fire. Consequently, it is probably correct to associate the hissing of ball lightnings with a dissipation of electricity.

Path followed by ball lightning

In a large number of cases (1, 8, 13, 14, 26, 29, 42, 47, 64, 65, 71, 88, 93, 107, 122, 143, 145, 157, 170, 171, 185, 194) the ball lightning is suddenly observed in the open air, partly at considerable heights, as can be inferred from statements like "the ball dropped out of the sky" (16, 88, 111, 170 and others), and partly at small distances from the earth's surface, above buildings and trees, in streets, etc. (29, 64, and others). In one case (107) it is mentioned that the ball did not come out of a cloud but was apparently formed between the clouds and the earth's surface. In other instances the ball lightning originates from a cloud (24, 41, 94, 115, 133, 159, 195, 197, 199, 206). Not all ball lightnings reach the ground. 8: I thought the ball would penetrate into the dung heap; however, when it had fallen down to a height of 3 feet above the heap it assumed a completely horizontal trajectory; 93: up to a height of 10—15 m above the ground; 94: falling out of a cloud to about half height; 122: down to a height of 4 m; 115: to the height of the roof, and others. In certain cases the ball reaches the ground. 95: the ball hit the ground; 107: it reached the ground; 111: after the ball had jumped to the ground; 143: the ball slowly descended down to the earth's surface; 199: just below the cloud cover a ball was formed which could be followed along its entire path down to the ground in the form of a floating body. Before reaching the ground other ball lightnings enter buildings and so on (1, 13, etc.).

The ball lightning does not always pass from a cloud to the earth's surface, but at times, as in the case of ordinary lightning, can also pass from one cloud to another (159, 195). A further example can be found in Arago 4, 171: after a dreadful thunderstorm, when in the whole sky only two clouds could be seen not far above the horizon, Nicholson suddenly saw in the vicinity of Wakefield meteors, which were similar to shooting stars, plunge from the upper cloud. There are also cases in which balls have been observed shooting up into the air. 3: the fireball ascended upward with a noise; 5: a fireball lifted up toward the clouds at an angle of 50—60°; 35: the ball, which was formed on the street, separated

[1]) Le Cosmos, 23, 550, 1863.
[2]) Berlin 1912, p. 143.

itself from the ground and rose above the houses; 76: the ball ascended to a height of 16—17 m above the sea; 87: the ball roared upward. In these cases the balls apparently originated from the earth's surface. A frequent occurrence is also the rising of the balls after they reached or came very close to the ground. 42: the ball descended into the garden, floated a few moments over the lawn like a soap bubble, and then suddenly rose again. 62a: the ball descended right into the middle of a grass-covered plot; whether it touched the ground could not be accurately established; immediately thereafter it rose again. 111: as the ball plunged to the ground it split into two small balls; the latter ascended into the air again up to the height of two adjacent chimneys and then disappeared. Further examples can be found in 8, 15, 171, 176.

In closed spaces or near parts of buildings, such as drainpipes, walls, etc., a similar rising or subsequent rising, as the case may be, is also encountered. 27: the ball lightning knocked against the edge of the roof of a shed, climbed upward and then moved toward the upper side of the roof edge. 173: the balls rolled down both sides of the gutterpipe until they vanished at the roof edge. 174: the luminous mass lifted somewhat into the air at the other corner of the room; 2: the ball traversed the yard, penetrated into a shed, and climbed up the adjacent wall.

Besides cases in which a single downward and upward movement is reported, we also encounter situations whereby the balls, partly upon contact with other objects, partly in the free air, bounce up and down like elastic bodies. 207: the ball struck the feet of a young girl, then rebounded up to the ceiling and moved up and down with moderate regularity, whereby it alternately touched the ceiling and the feet of the young girl; 30: the ball oscillated up and down with an amplitude of 4 cm; 2: the ball hopped through the kitchen; 167: rapidly rotating, bouncing disk; 178: the ball danced up and down; 189: the ball oscillated at least three times up and down in the glass chimney. Further examples are 9, 37b, 42 (cited on the previous page), and Arago 4, 36.

It seems also a proven fact that lightning balls often come to a stop along their path. An illustrative description of this property is given in
28 29: suddenly, in the vicinity of the church steeple, I saw a glowing white ball, which slowly descended along a zigzag path and came to a stop for a short time at the top of the belfry; it then moved slowly along a horizontal path into the tower and disappeared. After a few seconds the ball came out of the tower again — likewise horizontally — and slowly descended along a zigzag path toward the site at which I was standing until it came to a stop in midair about 5 m above the ground and approximately 10 paces away from me; several seconds later it descended right down to the ground. A similar situation is described in 209: the ball threatened to penetrate into a shed, but instead, after several moments' hesitation, it plunged into a drinking trough; 86: it seemed to stop for a few seconds in the middle of the room, but then continued to roll onward; 210: the ball seemed to stop for a few seconds beside the feet of the tailor, who watched it closely. Further examples can be found in 4, 16, 76, 90, 165, 187. There are instances where balls have been observed for various periods of time at some place without moving or before they started to move. 65: I saw in front of me a round flame which floated in the air above the middle of the floor. In 168 the ball allegedly stopped for five minutes on a wall in a room, whereby it was presumably hanging on the wire of the electric bell. It should be

pointed out, however, that according to other time data on the duration of ball lightnings the time interval of five minutes seems too large, so that here a printing error in the relevant publication probably occurred and the time should have been 5 sec.

The above examples give ample evidence that the path of ball lightnings is by no means linear, except where the latter applies at the most to balls dropping out of clouds toward the earth's surface, whereby the path is in part described as nearly vertical (53, 194), or to balls moving from one cloud to another (41, 99, 159). Nevertheless, there is one instance, where the ball followed an arched path from a cloud to the earth's surface (68). However, as soon as the balls come near to the earth's surface, in closed spaces, in the presence of bodies of differing electrical conductivity, the unsteady and inexplicable movements take place which determine the paths of the ball lightnings.

Besides cases in which the ball reascends into the air, we encounter other sudden changes in direction, or the path is continuously curved. In 29 the zigzag path was already mentioned; in 46 the ball went around a corner and passed a portal. 95d: the ball streaked down toward an iron rod lying on the wall, then jumped onto the ground and passed a distance of several meters over the ground; suddenly it changed direction and entered into a vestibule, traversed the latter and then plunged onto the street. 187: the ball rolled down the wet roof and then made a ninety-degree turn.

It is, of course, impossible to cite all the seemingly capricious changes in motion for each case. It should merely be pointed out that in enclosed spaces the motion of the lightning ball is frequently described as circular; for example, 118: the ball circled around the kitchen; 55: circled around the table; 37: rolled about the threshing floor; the same applies to 109 and 153. A peculiar motion was displayed by two balls initially connected to one another by a string of beads (181): whereas the upper ball at first followed a horizontal path, thus maintaining a constant height above the ground, the lower ball descended slowly. Only later did the upper ball also exhibit a slow downward movement until it faded.

Presumably the sudden changes in direction can be attributed either to horizontal and vertical air currents or to the effects of electrical conductors. However, when investigating the behavior of lightning balls as regards wind, we immediately strike upon contradictions, as illustrated by the following examples. 51: During the thunderstorm, which approached from the west, a strong air draft passed from the window through the kitchen and out via the vestibule. The "golden egg" moved slowly at a close distance to the floor with the tapered portion facing backward and followed the draft out of the vestibule; 68: from the northwest, from which also a fairly strong wind blew, the luminous ball described an arched path in our direction; 122: the ball slowly descended along the slant of the falling rain; 208: the ball was driven by a gust of wind into the room; an air current carried it outside again; entrained by the wind, it approached a group of rocks. Exactly the opposite behavior is mentioned in 13: the ball followed a slanted path from north to south (from a height of 300 m), exactly opposite to the wind direction; 76: the ball started to move in the upwind direction; 181: the balls moved toward the northeast; at the observation site (about 1 km away) the wind was northerly; 210: the ball displayed a tendency to veer away from air currents (observed in a room). A definite conclusion can hardly be made owing to the limited number of examples. However,

the fact that in relatively many cases the ball lightning enters via an open window or open door (17 and 7 cases, respectively) or leaves the room again via an open window (6 cases) or door (4 cases) could constitute further evidence that the motion of the ball lightning is influenced by the wind; consequently, it should be assumed that the ball followed the prevailing air currents. The motion of the ball in 28 can also be associated
130 with the influence of air currents, especially since a few seconds after the ball entered the belfry a bell was heard ringing, which the observer nevertheless attributed to the effect of the lightning ball.

However, in the same way the above case could involve an electrostatic attraction of the ball to the metal of the bells, the numerous cases in which the lightning balls pass through chimneys are probably attributable to the electrical conductance of the flue gases. In 15 cases of the present collection (2, 12, 37 c, 43, 54 b, 55_5, 55_8, 57, 80, 95 b, 111, 144, 159, 203, 210) the ball evidently entered the dwelling via the chimney, while in four cases (135, 169, 201, 210) it left via the chimney — in the last case it left the same way it had entered. The example in 189, where the ball oscillated up and down three times inside the glass chimney, also belongs to this group. In other instances good conductors of electricity also serve as a path for the lightning balls. In 22 and 137 the lightning followed a hanging lamp, in 23 the ball slid along a telephone cable (likewise in 59, 66, 136, 168, 185). Whereas in these cases the ball more or less slavishly creeps along electrical wires, in 152 we read: the ball cautiously hovered about the telegraph cables, at times approached, at times passed along and at times moved away from the latter; in this way it slowly reached the vertical pole, which served as a support for the cables, and there, following a downward slanting wire, it suddenly plunged into the nearby street. Lightning rods also serve as a path (24, 155, 175); the same applied to drainpipes (38, 55, 173, 200) as well as to the poplar in 202. In 154 the ball descended along a portion of the Eiffel Tower; in 89 it moved toward a hot-plate; in 113 the origin was the point of an iron support on a roof: in 95 the objective was an iron rod lying on top of a wall onto which it "plunged." Balls have also been observed over water. 142: the ball (whirlwind?) traversed the river and in doing so caused a pillar of fire several meters high. Often the balls move along roofs which are presumably wet at the moment of observation (in a few cases this was explicitly mentioned — 27, 113, 126, 200); 9: the ball fell onto the wet pavement; 40: it fell on a wet spot of the roof; 127: came to rest on a flooded meadow; 36: rolled along a wet forest road. In 125 the outside of a chimney served as a path, in 6 the varnished wall-paneling of a room, in 9 a 30-m long fence, in 174 the corner of a wall. In 187 the ball jumped from one chimney to another; in 132 from the gas bracket in one room to a gas bracket 6 m away in another room; in 95 d the fireballs, attracted by the iron spikes of a railing, jumped from one
131 spike to another. In other cases the balls rolled or moved along the ground, streets, fields, meadows: 18, 20, 28, 54 a, 67, 95 d, 128, 140, 176, 182, 202, 205.

The ball lightning at times also creeps along the bodies of humans and animals. 3: the ball moved toward the bare feet of the fire and disappeared beneath her clothes; it appeared again in the form of a ball at about the middle of her bodice. The opposite path was followed by the ball in 58. In 78 and 84 the ball lay on the back and the breast straps of a horse, respectively. However, it seems that the lightning balls display a more frequent

tendency to veer away from humans and animals. 177: the ball, which entered via the window, circled around a young girl who was sitting in the room and went out of the window again. 135: the ball rolled over the floor, turned toward the young girl, described an ascending spiral-shaped path tightly around her and then jumped toward an opening in the nearby chimney. Further examples (see also the section on physiological effects above) are 2, 12, 71, etc. Here we thus already encounter cases, whereby the lightning presumably avoids relatively good conductors as the result of electrostatic repulsion. Even metals seem under certain circumstance to have no influence the path of lightning balls. 12: the ball traversed the kitchen along a straight path, without striking any of the iron pots; 177: neither the drainpipes of the closely spaced dwellings in the alley, nor the electrical wires in front of the window, nor metallic objects in the room, nor even the metal handle on the window attracted the ball; 191: the ball moved between two telephones and passed a large metal chandelier and a bundle of wires and pipes; 174: the path of the ball was not altered due to the presence of metallic objects on the table; likewise, the ball moved between two persons who were sitting at a distance of 40 cm from one another. In 202 the ball sought its way between water puddles.

Most peculiar is the phenomenon that the balls moving in closed spaces — in 48 cases ball lightnings traversed rooms — as well as in the open air as a rule do not travel along the ground or along buildings, but rather float freely through the air, constantly maintaining a certain distance from objects or structures. This behavior is borne out by the following examples: 49: the ball hovered immobile at a height of about 1.2 m above the floor; 65: in the middle of the floor at a height of 1 m the ball approached the kitchen from the vestibule; similarly 179; 151: the ball passed at a height of 1 m through the vestibule toward the kitchen; 208: the ball circled around
.32 the room like a soap bubble, without touching any object; 210: the ball moved slowly through the room at low height above the floor-tiles. Further examples are 51, 54 c, 114, 120, 180, 191. The following examples apply to ball lightnings moving in the open air. 68: the ball crossed the street at a height of 1 m; 27: the ball moved parallel to the street at about head height; 148: the meteor moved above the ground and down an entire street; 190: the ball lightning was about 40 cm above the ground; 124: the ball lightning whizzed past at the height of a man above the ground. Further examples can be found in 46, 74, 83, 95 d, 110, 123, 146, 167, 184, 186.

It was already pointed out that the lightning balls frequently traverse rooms after gaining entry via windows, doors and chimneys. In certain instances they leave the room along almost the same path as when they had entered. 1: a fireball fell out of the sky, entered a door, rolled into the house and then left again via the door and entered the street; 20: the ball crossed the threshold of the front door, the hall, the threshold in the living room, where it turned around and left the same way it came, whereby at all times it moved along the floor; 153: a ball lightning penetrated into a dwelling, made its way to a telephone and then calmly turned around and left as it had come; similar instances are found in 50, 177, 210. In other cases lightning balls appear in rooms, but the report does not indicate or the observer himself is unaware how the balls entered; in certain instances it cannot even be established that the balls actually entered from the outside. Such an example is given in 192, where it was alleged by an eyewitness that the ball penetrated into a closed-off veranda and from there entered the guest-room through a likewise closed-off wall partition

consisting of window panes and wooden paneling. According to the observer, L. Weber, this phenomenon could be ascribed to an illusion on the part of the observer, insofar as the path of the ball did not start outside the veranda, and that the strongly electrified wires in the veranda as well as in the guest room liberated spherically shaped luminous forms. In a second, somewhat similar case (147) the ball lightning allegedly entered a room via a closed window without damaging the latter. In other instances the lightning balls apparently penetrate into obstacles, "disappear" and then reappear at the other side in the form of a ball. They slip through keyholes (207), or cracks and slits (159); 191: like a mouse it sought a crack in the closed door and disappeared; 203: the ball passed underneath a door,
33 whereby it tore loose some wood splinters. 51: since the door was closed, the ball suddenly ascended somewhat and passed through an opening filled with moss to the outside, whereby the moss was dislodged. In 210 the ball made for a hole in a chimney which was covered with paper, peeled the paper off without tearing it and ascended the chimney; a similar case is described in 135. These examples serve as a firm basis for the assumption that ball lightnings frequently choose air passages.

Whereas in 147 and 192 the window, through which the ball lightning entered, remained intact, the ball in 124 allegedly broke a hole the size of a fist in the window pane through which it passed into the open air. Again, in 22 the ball made a circular hole in a window pane, while the remaining panes were broken. It remains to be established whether lightning balls could actually have produced such effects or whether it would not be more probable that an ordinary streak lightning accompanying the ball lightning was the actual cause (in 22 the prevailing conditions point to such a possibility). Perhaps the mechanical penetration in other cases is only apparent, while in reality the ball lightning merely followed a metal object (nail).

The path length can be quite considerable, even when neglecting those cases in which the ball lightnings reach the earth's surface from clouds. In 33 the ball moved from a poplar struck by lightning along an almost horizontal path to a chestnut tree 840 m away; 181 it moved two minutes with a horizontal speed of 1 m/sec, i.e., over a distance exceeding 100 m; in 183 it entered via a gate into a farmyard, traversed the washhouse, leaped over a wall and exploded outside the yard. Similarly, in 208 the ball covered the distance between the hotel and the vestibule in one minute.

This seemingly contradictory and on first sight incomprehensible behavior of ball lightnings can be afforded a certain regularity in the following way. On the basis of the reports it follows that in most cases the ball lightning displays a preference for air passages, which under certain conditions can be influenced by wind, over other paths or even good conductors. It thus exhibits a behavior similar to that of Tesla currents, which avoid good conductors owing to their high self-induction. Hence the ball lightning enters via a window opening, a door, a narrow cleft, or even via a keyhole and, particularly, via a chimney with the ionized flue gases. Hence it circles about rooms without coming closer than 1 m from the floor or walls. Hence most of the ball lightnings are observed floating in the air. Closed spaces, which, however, are accessible via some air passage, apparently exert a special "force of attraction" on the ball lightning. After the ball
34 has made the rounds in the room, however, it seems that the latter loses its force of attraction, whereby even a "repulsion" is frequently recognizable,

since the ball lightning very often retreats again along the same or at times along another path. Perhaps the reason for this lies in an ensuing change in the electrical conditions of the air in the room. Noteworthy in the case of freely floating ball lightnings are the vertical oscillatory movements, which in closed spaces vary in amplitude from several centimeters to the distance between floor and ceiling. In the open air the ball is often described as performing a hopping movement; this is due to the horizontal motion which occurs in conjunction with the vertical oscillations. Occasionally this oscillatory movement merely consists in the ball dropping out of the cloud, nearly reaching the ground and then ascending again.

Simularly, certain changes in potential may have the effect that the ball lightning suddenly displays a preference for good electrical conductors, that it touches the floor, settles on iron objects, plunges into water, etc. The ball lightnings which settle choose good conductors along which they roll, metal objects such as, for example, drainpipes, and also the human body, while the freely floating balls maintain a certain distance also from the latter (the human body is a good conductor of electricity).

Speed

As in the case of the path of ball lightnings, the speed of the latter also displays wide differences and fluctuations. In only very few cases is the speed described as constant (59 b, 94, 107); usually the motion is either accelerated or retarded. The individual data on the magnitude of the average speed are all contradictory; in fact, the values vary between 0 (for a ball lightning temporarily at rest) and seemingly ∞ (when the ball lightning changes into an ordinary lightning). When in one instance (46) it is asserted that the ball passed around the corner of a street at a walking pace, while elsewhere (17) the fireball streaked downward at extremely high speed, then a basis of comparison seems totally lacking. Moreover, the above two examples were not singled out but selected at random. Examples of temporary states of rest were already given above. The other descriptions of the speed are partly of a general nature — slow, fast, etc. — and are partly compared to velocities which are known; some of the data are based on direct measurements and observations. The most frequently occurring designations are slow, moderate, fairly or quite slow, at low speed (42 cases). In 11 cases the speed is designated as high; in 95 c the balls were entrained by a twister, while in 17 and 95 the ball streaked down at an extremely high speed from the sky.

More illustrative than the above generalized descriptions are the comparisons made with known velocities. 133: the ball fell quite fast, but slower than an ordinary lightning; 20: the motion of the ball could not be compared to the speed of an ordinary lightning; 199 a: the luminous mass descended toward the earth at low speed, so that the spherical form could be clearly recognized. The speed of the ball lightning is compared to that of a pedestrian in 46, 51, 183, to the speed of a bird of prey in 83, to a downward gliding bird in 122, to a mouse in 6; in 10 the inquisitive crowd followed the ball at a pace comparable to that of forced march. In 69 the ball traveled at the speed of a locomotive, of a firmly cued skittle ball in 36, as if it had been thrown in 52, 59, as if it were attracted by gravity in 133, 121; it "wandered" down the street in 148; slid down the stairs in

48, rolled up the stairs in 205. In other cases the ball moved at such a speed that it was possible to keep up with it when running (74), that the observer could keep his eyes fixed upon it (20, 86, 124), while in 123 a second person could be called to the window and could see how the balls climbing up along a drainpipe vanished, or, as in 22, it was possible for a person standing nearby to move out of the way of the ball.

The following data are based on measurements and estimates. 55_2: the ball covered the distance between the window and the middle of the room in two seconds; 62 a: the ball covered the first 26 m of its path in two to three seconds; when it ascended, its speed was much greater; 33: the ball covered the distance of 840 m in three to five seconds; 154: in two seconds it covered a distance of 100 m; 187: five to six seconds for 12 m; 191: five to six seconds for 15 m; 209: from the moment the lightning struck the oak tree until the fireball disappeared in the drinking trough (300 m away) more than one minute passed; 181: the horizontal speed of both balls was hardly greater than 1 m/sec; 200: the ball moved at a speed of approximately 2 m/sec; 139: the lower limit of the speed was calculated as 30 m/sec; 70: five to seven seconds from the cloud to the earth; 211: the speed was moderate and was estimated at not more than 2 m/sec.

If these seemingly contradictory data are to be systematically analyzed, then the reports must be classified according to groups, depending on whether the lightnings proceed from clouds to the earth or between clouds, or whether the ball lightnings move through closed spaces or near the earth's surface, or describe a more or less horizontal trajectory. Accordingly, the speed in the first group is definitely lower than that of an ordinary lightning but still appreciably higher than that observed in dwellings, etc. The speeds in the last group should not exceed a few meters per second (10, 36, 46, 51, 52_2, 122, 181, 187, 191, 200, 209, and the large number of cases in which the speed is described as low). The most frequently occurring value is 2 m/sec, which indicates also in those cases where more precise data are not available that the observers could recognize and record all the details. Nevertheless, the value given in 33 is completely out of context here, so that one is tempted to regard the time of 3.5 seconds as a printing error and to assume that it should be 35 seconds, even though this would result in a significantly higher value.

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On the other hand, the speed of ball lightnings observed at great heights must be considerably higher than several tens of meters per second, which would then agree with the data given in 139 and 154. However, in these cases as well the motion is occasionally described as relatively slow, though here the observer probably effected an unintentional comparison between the speed of the ball lightning and that of an ordinary lightning. If the velocity of the vertically descending balls would be of the same order as that of the balls on the earth's surface, then the duration of the phenomenon would be so long that the observer would surely bring this to expression in his account. It remains to be pointed out that in isolated cases the speed of the ball upon ascent is designated as being lower than upon descent (42 and 62 a).

Duration

The duration of ball lightning is substantially longer than that for ordinary lightning. Whereas our visual perception does not enable us to assess the

duration of [redacted]ghtning, ball lightnings move so slowly that their movem[redacted]t in [redacted]all cases can be clearly followed. Nevertheless, the observers gi[redacted] widely differing values for the duration of a ball lightning; times varying from one second up to five minutes or more are mentioned. However, if we classify the 58 instances in which the duration is specified into groups, then by far the greatest position falls in the group from one to five seconds (30 cases). To this group we can thus also add cases, such as 16: owing to my immediate call he saw how the ball came to a stop and suddenly vanished; 117: everyone called out in unison: look!; at the same moment the ball exploded; further examples are 86, 54, 45, so that, all told, there are 35 cases which belong to this group. Of the 30 explicitly mentioned times 14 fall in the interval from one to two seconds. 6 in the interval from two to three seconds, three in the interval from three to
7 four seconds, four in the range of five seconds and likewise four in the range of several seconds. For durations longer than five seconds there is a rapid decrease in the number of examples; five cases in the interval from 5 to 10 seconds, four in the interval from 10—15 seconds. Next, we consider a ball lightning with a duration of 40—50 seconds, which, as it were, forms a transition to the long-lived ball lightnings. Lightnings lasting from one to two minutes are reported five times, from two to three minutes once, three to four minutes three times, four to five minutes twice, several minutes once, and in one case (206) the fireball allegedly remained luminous for longer than a quarter of an hour! Of the ball lightnings with a lifetime of the order of seconds 33 were seen in the air, in part via windows from rooms and in part (11 cases) in closed spaces. In contrast hereto, the lightnings of longer duration were all, save one, seen in the open air. Here, of course, there exists the possibility of following the ball lightning along a longer path than in a room or via a window; this fully explains the longer duration of ball lightnings observed in open terrain. An illustrative example of the influence of the observation conditions is given in 208: the ball, which was driven by a gust of wind into the hotel room, moved about the latter for about ten seconds; then it was observed for another minute as it moved away from the hotel until it exploded.

Of course, all such assessment of the duration of ball lightnings should be treated with caution, since errors in the estimates are easily made when the observer is in a state of astonishment. For this reason times exceeding 1—2 minutes can hardly be considered as reliable. The second fireball, which in 206 was luminous for longer than quarter of an hour in the top of a tree struck by lightning, was presumably not a ball lightning but in all probability St. Elmo's fire; this is further borne out by the expression "bundle of luminous rays." On the other hand, the time specified in 181 — the total duration from the moment the upper ball was first observed until it faded amounted to two minutes; the movement of the lower ball lasted for about three-quarters of a minute — is by all means feasible, since the observation was made on a scientific basis, and, in fact, simultaneously by four persons. This assessment is also significant insofar as the lifetime of at least one of the two balls could be established. For the upper ball the lifetime was two minutes, while the lower ball was observed for $^3/_4$ minute until it disappeared behind a bush. Thus, on the basis of the existing data there can be no doubt that the total duration of ball lightnings can reach values of up to two minutes. This is an extremely high value compared to the durations of fractions of a second corresponding to ordinary discharges in the form of streak lightnings

(the duration of the partial discharges of an ordinary lightning discharge fluctuate between $^1/_{1600}$ and $^1/_{20}$ sec[1]). Even when an order of magnitude of 1—5 sec is assumed as normal for the ball lightning, this would still be extremely large compared to that of a streak lightning. This circumstance constitutes one of the factors which can explain that earlier there existed much doubt about classifying fireballs as lightning. In fact, as was borne out by the deliberations on the appearance and effects of ball lightning, these fireballs have little in common with actual lightnings; on the basis of their behavior they occupy a position between ordinary lightning phenomena and St. Elmo's fire.

DEVELOPMENT AND DISSIPATION

Development

Already in the analysis of the physical and chemical effects of ball lightning we repeatedly encountered the observation that ordinary streak lightnings occurred more or less at the same time and place as the ball lightnings, so that we were forced to conclude that on frequent occasions the alleged effects of the ball lightning were probably misinterpreted and in actual fact were merely associated with the effects of streak lightnings. Consequently, we are confronted with the question whether an ordinary lightning or an initial lightning discharge actually precedes the appearance of a ball lightning. This presumption seems to possess a sound basis in a large number of reports. 18: a powerful lightning streaked downward and then we saw three fiery balls; 65: after a powerful discharge I saw a fireball ahead of me; 58: the ball appeared one or two seconds after the thunder; the lightning struck the chimney of the house; 87: a lightning struck an acacia tree; immediately thereafter a large fiery ball appeared on the lawn in front of the acacia; 32: suddenly the house was shaken by a dreadful thunderclap; the lightning struck the ground 20 paces from the house; at the same time a fiery ball was observed in the middle of the room; 148: after a powerful lightning discharge a fireball appeared; 154: I saw how the top of the Eiffel Tower was struck by a lightning; at the same moment a fireball, slightly brighter than the lightning, descended from the top; 176: after a very vivid lightning flash a red ball was seen rolling over the ground in the garden; 190: directly after a lightning, which was accompanied by a dreadful detonation, I noticed a fireball about 3—4 m
139 ahead of me. 210: after a very powerful lightning discharge, but not immediately thereafter, a tailor witnessed how a fireball entered via the chimney; 129: the lightning struck the post office; lightning and thunder occurred simultaneously; P. saw a fiery ball on the premises; 112: first a fairly powerful lightning streaked downward and left behind a fiery ball at the point were it ended. — It would take too much space to cite all the relevant reports. Among the 214 reports in the present collection there are 106 which indicate with certainty, or, at least, with high probability, the existence of an initial lightning flash. (Here we should point out the difficulty encountered in the reports originating from the French literature, whereby the word tonnerre, which actually means thunder, is often

[1]) Science 105, 163—170, 1873.

erroneously used to mean foudre (lightning), so that it cannot always be established whether lightning or thunder is meant.)

An excellent example of the validity of assuming the existence of an initial lightning is given in 199: Only in the SE did such discharges occur frequently; these gained in intensity and repeatedly followed the same path which is probably due to the increased conductivity of the air along this channel. After another, very powerful discharge, there immediately followed a beaded lightning along the same channel. A few seconds later a lightning discharge followed the same channel. Shortly thereafter, at the upper end of the discharge channel, just below the cloud cover, a spherically shaped luminous mass appeared which descended at low speed toward the earth. A short time later, also after a powerful lightning discharge, the phenomenon repeated itself. After each powerful discharge a bright luminous ball could be seen at the end of the lightning channel facing the observer.

An equally substantial number of reports offer no evidence, or at least nothing certain, concerning the occurrence of such an initial lightning discharge. In many cases no details whatsoever are given on the meteorological conditions prevailing during the appearance of the fireballs; at the onset the existence of a fireball is already established; for example, 135: a ball lightning appeared in a room and approached a young girl; 205: two children, who were playing on the street, suddenly saw a fireball. Very often it is merely reported: a ball lightning was seen during a violent thunderstorm (165, 187, 194 and others). Thus, lightnings certainly occurred here as well; however, one is not justified in speaking of an initial lightning in these cases or in those in which the ball lightning was observed from a large distance, or when several lightnings streaked
40 downward. In the large number of accounts given by laymen it is not surprising that no mention is made of the accompanying phenomena, which are of special interest to the physicist, since the observer's attention is mainly caught by the external appearance of the unwelcome guest and its actual or apparent effects, and in certain cases, its path, while factors relating to its creation are usually of secondary importance to him. However, the lack of such data may not be regarded as proof of the absence of an initial lightning. Apart from the fact that the observer does not deem it necessary to establish explicitly the precedence of a lightning, such a lightning could very well have escaped his attention. At any rate, however, such "neutral" reports should not be included in the discussion on the question concerning the initial lightning.

Nevertheless, there exist a few reports from which it can be inferred that the occurrence of the ball lightning was not preceded by a spark discharge, while in an even more limited number of reports it is actually stressed that the ball lightning was not directly preceded by streak lightning. The following reports can be included in the first group: 94: I was wondering why no lightning discharge occurred for such a long time, when suddenly a ball emerged from the cloud. The ball was the last discharge; only three or four glowing-white lightning flashes struck the earth at long time intervals during this thunderstorm; 145: the lightnings appeared at very short intervals; then, after a pause of a few minutes I saw a fireball; 122: I was under the impression that the ball had formed itself from the luminous rain before my eyes; 198: I observed a ball lightning, which was preceded several minutes beforehand by other lightning streaks.

The nonexistence of an initial lightning is explictly mentioned in the following reports: 74: bright summer lightning could be seen and it was sultry; then I suddenly saw a fiery ball fly over my head; 173: the appearance of both balls was not immediately preceded by lightning; 197: I saw a luminous ball without the prior appearance of lightning; 181: suddenly a luminous, spherical mass was seen which was not preceded by any other type of lightning. Further, in the region of the atmosphere where the the discharge took place no lightning was observed during the entire thunderstorm; 133: although neither lightning nor thunder was perceived, the weather was oppressive and sultry; suddenly I saw a large fireball at the top of a post.

As regards the above assertions it should be added that the accounts in 74, 173 and 197 were reported several years after the phenomenon in question was observed, the last one on the basis of questions put to the observer by the author of the report; consequently, these reports cannot
11 be considered as absolutely reliable in this respect. Furthermore, in 173 it is stressed that a lightning did not immediately precede the appearance of the two balls, but it still remains an open question what is meant here by "immediately." In 145 mention is actually made of a pause of several minutes between the lightning flashes and the fireball; the latter, however, appeared in exactly the same place where, beforehand, the straight lightning flashes occurred. On the other hand, in 94 and 108 the absence of an initial lightning seems fairly certain, since here it is asserted that the time interval between the last lightning and the appearance of the ball lightning was long (even up to several minutes). Also in 113, which obviously involves a ball lightning similar to St. Elmo's fire, the initial lightning is apparently absent. The account given in 181, however, is fully reliable. Here, four scientists concurrently established the absence of an initial lightning discharge and in addition confirmed that during the entire thunderstorm no lightning was seen near the relevant sites, where the ball lightning was observed. Consequently, in this case the absence of a visible initial discharge must be assumed as verified. However, even when in the above case and perhaps in a few other instances a visible discharge had not preceded the ball lightning, the number of such cases is still much smaller compared to the cases in which the presence of an initial lightning is confirmed; consequently, one is justified in assuming that as a rule the ball lightning is initiated by a streak lightning.

It occasionally happens that a ball lightning seemingly develops directly from a streak lightning, i.e., "the lightning terminated in a fiery ball." 79: a lightning, shooting straight up into the sky, terminated in a ball, which suddenly faded and then burst like a rocket; 112: an ordinary intense lightning streak developed into a fiery ball at the point where it terminated; 139: horizontal lightnings emanated in all directions from a small reddish spot in the cloud; one of these lightnings suddenly initiated a ball which shone with moderate intensity through the lower cloud layer; 184: a straight, wide, dazzling white streak, which emanated from the ground, was enveloped at the upper extremity by a luminous ball the moment it reached its maximum height. July 30/31, 1892, Gleisdorf (Mitt. Nat. V. Steiermark, 30, 426, 1893); a few lightnings were seen which disintegrated into innumerable balls. This peculiar development of ball lightnings directly from streak lightning seems, insofar as this conclusion can be justified despite the limited number of examples, to be a characteristic property of so-called return strokes, which emanate from the earth's surface.

Ball lightnings can also occur at the extremities of the branches of a lightning. An excellent example of this process is given in 55: a lightning flash of extraordinary brightness illuminated the entire city of Amiens. Although it was the sole lightning of this thunderstorm, it nevertheless struck the city at several places quite remote from one another, and, in fact, "in the same exceedingly peculiar form of fiery fragments, which seemed to represent on a reduced scale the very rare form of ball lightning." The ball lightnings described here also possess in part a size which differs greatly from that of the majority of balls: a fireball the size of a hazelnut; of 2—3 cm diameter; flames the size of an egg; balls of flames ranging in size from that of an orange to that of an egg; a nut-sized ball. This circumstance likewise indicates that here we are dealing with balls which originated from a branching of the lightning, if not at the extremities of the branches themselves. The small ball in 198 could also have been the extremity of a branch of the main discharge. Frequently, alleged ball lightnings can be associated with certainty with such an intense extremity of a streak lightning. Let us consider an example which is not included in the present collection[1]): the lightning appeared in the form of a bright flash straight down to earth. Upon impact against the top of the gable a fiery ball separated itself, as it were, from the wall, rebounded laterally and burst near the ground.

Usually the ball follows the initial flash in very close sequence, often after only fractions of a second. A time interval of this order must also be concluded in cases where it is alleged that the ball was observed "at the same time" or "directly after" the lightning and thunder, respectively. In 210 — after a very powerful lightning, but not immediately thereafter — the time interval is probably of the order of a few seconds; likewise in 199; shortly after the flash a ball-shaped luminous mass was formed. Occasionally the time interval is actually specified: half a second after the lightning (108), 1—2 seconds after the thunder accompanying the lightning which struck the house (58). In 117 the time interval even reaches 20 seconds: just as I had reached a count of 20 seconds between the appearance of the lightning flash and the thunder, we all saw the fireball. However, it does not seem unfeasible that this time interval can be exceeded and that the time between the initial flash and the ball lightning can be of the order of minutes. 198: other lightning flashes preceded the ball lightning by several minutes.

The question concerning the distance from the initial lightning at which the fireballs occur can also be more or less elucidated on the basis of the existing reports. In one instance (199) it was explictly mentioned that the ball lightning followed exactly the path of the preceding lightning flash. In 30 other cases among a total of 55, in which similar assertions are made, the lightning struck the same building in which the fireball was subsequently seen; on two occasions it is alleged that intermittent zigzag flashes passed through those parts of the clouds where the ball lightnings were seen. In four cases the streak lightning terminated in a ball; four times the lightning struck "in the immediate vicinity," seven times "nearby." In 79 the ball was observed on a meadow in front of a house struck by lightning; twice the lightning struck another house; in 157 it was as if the entire ship was afire while the fireball was seen on deck; in 61 the ball crept along a telegraph wire, the lightning having demolished the nearest telegraph

[1]) Weber, L. Op. cit. p. 14.

pole; in 189 the observer was not under the impression that the lightning had struck in the immediate vicinity. In three cases numerical values are given. 32: the lightning struck a tree 20 m away; 128: 30 m from the building struck by lightning; 137: the lightning simultaneously struck two adjacent houses separated by 15 m from each other; in one of the houses a ball lightning appeared.

The following inferences can be made on the basis of the above discussion: ball lightnings in part develop within clouds and can become visible as they emerge from the lower cloud layer, in part in the open air and apparently also in closed spaces, and in part settle on protruding objects. In a very large number of cases their appearance is immediately preceded by an ordinary lightning — the initial flash — at whose point of impact or in the close vicinity of which the ball then appears. In certain cases, however, the absence of the initial lightning is confirmed.

Dissipation

Highly contradictory data exist on the dissipation of ball lightnings. According to a considerable number of reports this process can proceed without creating any noise or leaving any trace. There are 40 cases in which it is explicitly mentioned that the fireball disappeared without causing noise, leaving traces, etc. Occasionally the process is described as "extinction," or we read: the ball "dispersed"; in one case: the phenomenon lasted 2 seconds, then nothing was heard or seen. In addition, there are several cases which would lead one to assume that the noiseless disappearance of the ball is probable (for example, 22 and 177). It is, however, quite possible that in certain cases the final phase of lightning balls seen in closed spaces or from rooms could not be observed. Nevertheless, those cases, in which a fireball disappeared via a keyhole (207) or a practically invisible opening in the floor (58) or in the door (51) and the like,
144 or whereby the subsequent course of the fireball was hidden from view by obstacles, such as buildings, are offset by cases in which the noiseless final phase of the ball was directly observed. Let us consider a few examples. 154: a fireball slowly descended from the top (of the Eiffel Tower) to the intermediate platform of the third level, where it disappeared without leaving a trace; 104: the two persons were standing barely one pace away from the phenomenon, which after one second disappeared without causing the slightest damage; 181: the upper ball suddenly faded out; 48: the ball slid down the stairs and faded out right before the feet of the observer; 211: the moment the phenomenon touched the ground it disappeared into thin air without a bang or noise.

The disappearance of the ball can take place in part in the air (16, 45, 76, 77, 139, 158, 162, 181, 197), in part after coming into contact with objects, for example, the ground (54, 67, 107), floor (211), drainpipe (113), and particularly often when making contact with water: water tank (128), puddle (27), water surface (209), cistern (159), brook (176), wet pavement (29), a garden transformed into an extensive water reservoir by a cloudburst (38).

In certain cases the disappearance of the lightning balls is accompanied by a noise similar to that considered as an accompanying phenomenon of ball lightning. 29: when the ball touched the wet pavement, it burst into flames with a crackling noise and disappeared, to my surprise,

without leaving any trace whatsoever; 36: the ball disintegrated into a shower of sparks. Except for a dazzling brightness the burst did not cause any bang; 87: the ball roared up into the air and vanished with a crackling noise; 54: the ball disappeared with a slight buzzing noise; 56: the ball faded out with a hissing noise; 165: the ball vanished with a faint noise of rapid discharges, etc. A moderate bang is sometimes also heard. 79: the ball faded and burst like a rocket; 49: the ball disappeared with a bang like the report of a pistol; 65: the round flame died out with a small explosion: it sounded like a blasting cap; 79: I saw the ball vanish with a bang.

On the other hand, in many instances it is expressly mentioned that the ball lightning exploded, or as is often the case, burst. In 62 reports, the ball burst or exploded or flew to pieces with a dreadful cracking noise (61), with a noise like the discharge of a cannon (37 a), burst into pieces (37 c), shattered with a short but sharp bang, as if a rifle were discharged a few meters in front of the house (198), exploded with a loud detonation
15 and intense emission of light (117), with a frightening bang (213), etc. However, from all the above reports it is not clear how one should imagine this explosion. In many cases one is tempted to believe that it is the accompanying acoustic effect which creates the impression that the ball explodes, the more so since in a number of cases the observer did not see any explosion but only established that a detonation was heard after or with the disappearance of the ball. 173: the disappearance of the ball was almost simultaneously followed by a bang. In 122 it is asserted that the ball vanished with a very loud bang, while no flying bits or pieces were noticed; 30: after a few seconds had passed, a loud bang followed, and the ball vanished without any of us knowing where it had gone. Further examples can be found in 5, 10, 42, 49, 73, 138, 171, 214. In many of the above cases we cannot exclude the possibility that the alleged explosions or the loud bang, etc., are associated with ordinary lightning discharges, perhaps even the initial flash itself; this could very well be the case when making allowance for the fact that the ball lightning is usually a short-duration phenomenon. This applies especially to 214: the thunder was heard at precisely the moment when the ball vanished; the sound, however, seemed to come from above rather than from the place where the ball occurred.

A clearer picture of the dissipation of the balls is obtained in those cases where the ball bursts with the emission of lightning streaks or where pieces and sparks are hurled about as the ball explodes. 14: a frightful detonation suddenly burst the entire envelope and the hellish machine inside emitted a dozen lightning streaks in all directions; one struck a house; 84: the ball exploded in the form of a lightning flash, which at first moved away from the animal but then jumped back and killed it; an oak tree in the immediate vicinity was likewise struck; 92: the fireball emitted ray-like lightnings in all directions which set nearly all the surrounding buildings afire; 93: the fireball burst and formed zigzag flashes which proceeded parallel to and toward the ground; 101: the ball exploded like a bomb; rays shot out in all directions; the principal ray struck a plot of land; 115: a whole bundle of rays emanated from the ball; 199: the ball disintegrated into 7—9 ray-like, outward emanating lightning streaks; 110: the moment the ball burst
46 it emitted a lightning streak toward the left corner house. Further examples are 44, 63, 64, 83, 91, 127, 141, 144, 149 and 179.

The occurrence of small sparks and flashes is, as was shown above, observed before the explosion of lightning balls. Consequently, this phenomenon need not be regarded as a characteristic of the dissipation process proper. On the other hand, the fact that in the above cases the ball lightnings emit lightning streaks upon exploding, which have the effect of ordinary lightnings, would render it feasible that the explosion is only in part apparent and that this illusion is caused by a new lightning discharge which terminates the entire discharge process. When several lightning flashes are simultaneously emitted by the ball, then this could be associated with a branching of the lightning. This interpretation is directly confirmed by the following report (85): after the first violent thunderclap a fireball appeared on the western gable which was immediately afterwards ruptured by a second lightning discharge, instantly setting the roof afire. In another case (96) it is reported: the ball burst with a dreadful bang, which was followed by a persistent thunder similar to an exchange of rifle fire. The resulting lightning spread out in all directions. This branching of the lightning upon explosion seems to occur fairly often—compare 14, 63, 92, 93, 101, 115, 199. The following cases also point to the probable presence of a final lightning discharge: 127: a frightful detonation marked the final phase of the ball, while it was impossible to say whether the luminous mass had actually exploded with the noise; it simply disappeared, that is all that can be said with certainty; 34: the ball exploded with the simultaneous occurrence of lightning and thunder; 149: then large sparks in the form of stars shot out of the fireball and finally a zigzag lightning darted out. At this moment an electrical pillar of fire blinded the observer and there immediately followed a powerful thunderclap; 151: shortly after the disappearance of the ball (beyond the field of view) a dazzling lightning flash occurred; at the same time a thunderclap was heard which sounded like the discharge of a cannon.

Also in other instances reports are given of an ordinary lightning in connection with the disappearance or explosion of the lightning ball, for example, 117, where the lightning split two trees before the house in question; 167: a powerful detonation followed, the disk disappeared; the lightning struck an oak tree on the side facing the ball lightning; 189: one second after the ball vanished there followed a frightful lightning flash which struck the church adjoining the house; 137: while the ball lightning
147 was spreading fear throughout the room, another lightning struck in the adjacent kitchen; 211: a few seconds after the phenomenon took place a powerful lightning discharge occurred nearby; the electric fuses in the room burnt out, the sockets melted and the lamps fell to the floor. When in 146 it is reported that the ball lightning moved at low altitude through the air, struck the top of an enormous oak tree and split it right down the trunk, then, as in 2, where a shed caught fire after the ball lightning disappeared with a loud crack, the effects of a final lightning could have been manifested here. Also 5, 30, 42, 40, 114, 118, 125, 184 and other less clear cases point to the occurrence of a streak lightning which terminates the ball lightning phenomenon.

Other reports explicitly deny the occurrence of a final lightning flash. 43: after the appearance of the ball, neither were lightning flashes seen nor was thunder heard; 186: the explosion in the second room took place, while no new lightning discharge was heard outside; 173: no other lightning discharge occurred after the two balls dissipated. Report 198 also belongs

to this group, since the next lightning struck directly behind the house in question only three minutes after the ball lightning burst.

It sometimes happens that a final lightning discharge follows the ball lightning and strikes the latter, thus terminating the entire discharge process. This final lightning flash could also clarify why the observer is occasionally under the impression of a strong increase in the light intensity when the ball lightning explodes.

The dissipation of ball lightnings sometimes involves a disintegration of the primary ball. 94: a dazzling white ball steadily floated downward along a vertical path. Halfway down it burst into six rocket-like luminous bodies, which described slightly diverging paths toward the earth and dissipated almost simultaneously along the last third of their respective trajectories; 113: the ball, which was observed 40—50 seconds on the point of an iron rod, suddenly split into three smaller balls which rolled along the roof; 63: a large luminous mass fell vertically downward out of the cloud and burst into several pieces which disappeared; 111: several persons witnessed a ball of 2 cm diameter descend from the sky which, after hitting the ground, split into two smaller balls. Further examples are 45, 115, 156. Report 156, however, probably involves the branching of an ordinary lightning, while 115 does not really seem to point to an actual splitting of the primary ball — the reporter merely assumes that a splitting probably occurred — but, here as well, provided the two balls separated by a distance of 500 m are in any way related to one another, the balls could have developed in the branches of a lightning flash. As opposed to Töpler[1]), the present author does not consider the emission of sparks as a splitting process. Consequently, the number of cases in the present collection where the ball splits into several pieces is not large. Nevertheless, this group can be supplemented by examples dating from earlier times which were not included in this collection. Let us cite two such examples: Arago. 4, 33: a person saw a fiery ball the size of a man's head which burst into four pieces in the vicinity of the church. (3 July 1725) 36: a short time after Phillip V marched into Madrid lightning struck the chapel. The crowd assembled there witnessed the entry of two fiery balls; one split into several smaller balls, which repeatedly bounced up and down like elastic balls and then disappeared.

In any event, the splitting of lightning balls is not a common process; it proceeds in part in the air, in part only when the ball strikes solid bodies. The smaller balls do not seem to display any significant differences in appearance from the primary ball; in 113 it is explicitly mentioned that their appearance was the same as that of the original ball; in 94 the observer was under the impression that the partial balls fell at a greater velocity (probably as a result of the smaller distance) and that the light intensity became weaker.

The converse case, whereby balls unite to form a larger ball, can also be substantiated by examples. In 59 it is reported: we suddenly saw flickering flames mixed with yellowish balls above the crest of the mountain. The balls moved toward a cable or wire, approached one another, and united into a larger luminous mass, which fell like an exploding rocket in the form of twisting reddish and blue balls. Here, as in 1, a splitting and reunification of the balls occurs. However, this phenomenon occurs even more seldom than the splitting process itself. A further example can be found

[1]) Met. Zs. 17, 550, 1900.

in Arago 4, 33, and Ders. Unterhalt. a. d. Geb. d. Naturw. 4, 170, respectively: on the night of April 14—15, 1718, the church at Cuesnon was struck by lightning and destroyed during a violent thunderstorm. Three fireballs were seen, each of which had a diameter of $3\frac{1}{2}$ feet and which, after uniting with one another, rolled with remarkable speed toward the church. This large, spinning mass of fire intruded into the church, killed
149 two of the four persons present, who were ringing the churchbells, and demolished the walls and the roof in a way similar to the destructive effect of a landmine; several stones were hurled a distance of 26 toises[1]). (The entire report, however, is very mystical.)

Finally, we may mention a rarely occurring form of ball lightning disintegration, whereby the ball transforms into a series of luminous balls. Such a phenomenon probably occurred in 122: many isolated sparks fell from the balls like glowing drops of molten metal. Report 170 indicates the occurrence of a beaded lightning which followed the ball lightning: the ball seemed to be hanging on a luminous "wire" which appeared above it.

The conclusions arrived at on the basis of the above discussions are summarized below.

EMPIRICAL PRINCIPLES OF BALL LIGHTNING

1. Ball lightnings are rare forms of spherically shaped electrical discharges (more seldom pear-shaped, etc.) which have a relatively higher incidence during winter thunderstorms, and which possess less force than streak lightnings.

2. The ball lightning usually appears as a red, luminous ball or hollow sphere of 10—20 cm diameter on a blue background and has a blurred contour. Occasionally, however, it can be dazzling white and have a sharply defined contour.

3. It makes a hissing, buzzing or fluttering noise.

4. Upon dissipation it often leaves behind a sharply odorous mist which is brown when viewed from the side, blue when viewed from above, but white when the air is saturated.

5. Its lifetime varies between just perceptible fractions of a second up to several minutes; most frequently the duration of ball lightnings amounts to 3—4 seconds.

6. The ball lightning can become visible after emerging from the bottom of the cloud, but can also develop in the free air on some solid object. Very often it is preceded by an initial flash, whereby the ball lightning is formed at the site where the lightning strikes or in the vicinity thereof; however, the absence of an initial lightning discharge is not a rare occurrence.

7. The ball lightning can dissipate noiselessly, with a soft bang or with a dazzling explosion, whereby numerous short streak lightnings are emitted in all directions. Occasionally it is terminated by a streak lightning (final lightning) which strikes the ball.

150 8. The speed of ball lightnings is very great when they appear at the base of the cloud and shoot down to earth (transition to streak lightnings). Near the earth's surface or in closed spaces the ball lightning moves at a

[1]) [An old French unit of length equal to 6 French feet, 6·396 American feet, or 1·949 meters.]

speed of approximately 2 m/sec. It can come to a stop for short periods of time, whereas lightning balls which develop on solid objects can remain stationary while emitting sparks and finally disappear (transition to St. Elmo's fire). At times the ball can be carried along with the wind, though usually its motion is independent of the prevailing air currents.

9. Occasionally several ball lightnings appear around the site where a streak lightning struck. A single large ball lightning can burst into several smaller balls. Further, it may happen, though very rarely, that two ball lightnings appear one above the other, are connected by a "string" consisting of small luminous beads, or that a short row of beads occurs with a single ball lightning (transition to the actual beaded lightning).

10. Freely floating and stationary ball lightnings seem to possess very diverse properties, but can, however, transform into one another. The free-flying balls create the impression of extremely high-voltage discharges of low-current intensity, comparable to the Tesla currents, while the stationary ball lightnings, on the other hand, seem to be at a lower potential and have a higher current intensity.

11. The free-floating ball lightnings have the red color of meteor trails in the stratosphere. They avoid good electrical conductors and usually follow air passages. They are "attracted" by the air in closed spaces; these balls enter the latter via an open window or door, and even through narrow cracks; however, they display a marked preference for entering via the flue gases of chimneys which have a better electrical conductance without self-induction, so that very often they emerge from the hearth and thus gain entrance into the kitchen. After the ball describes a few circles around the room the latter seems to lose its force of attraction and the ball lightning leaves again via an air passage, often the same as before, though at times along a new path. It poses no danger to humans, even when it falls in their midst, since it stays at a distance from the human body, the latter being a good conductor of electricity. At times it carries out two or three vertical oscillatory movements with an amplitude ranging from several centimeters to meters, whereby in the open air this vertical oscillatory motion is supplemented by a translational motion with the result that the ball performs a hopping motion. This oscillatory movement often merely consists in a single descent of the ball from the cloud down to a height of several meters above the ground followed by its ascent.

12. The stationary ball lightnings have a dazzling brightness and are white or blue in color; they settle on good conductors, preferably on the
.51 upper extremities thereof, or roll along drainpipes, etc. They heat the object on which they settle or along which they creep; they can inflict serious burns on humans when they pass along their bodies (at times underneath their clothing) and often have a fatal effect.

13. The transformation of a free-floating ball lightning into a stationary one takes place when, after a short hesitation, it suddenly plunges into water (i.e., a good conductor of electricity). Upon coming into contact with the conductor it can dissipate with an explosion or without creating any noise, but can also continue its existence in the form of a stationary ball lightning. Ball lightnings shooting down from clouds usually reach the ground, where they often explode.

14. The transformation of a stationary ball lightning into a free-floating ball consists in a mere lifting of the former, after which the ball lightning usually ascends along an oblique path toward the clouds, though, as a rule, it dissipates soon after it lifts.

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152 *THEORETICAL AND EXPERIMENTAL CLARIFICATION*

Considering the mysterious darkness which has shrouded the ball lightning phenomenon for such a long time, it is not surprising that the number of attempts at clarifying this peculiar form of lightning run into the dozens.

Nevertheless, despite the numerous approaches used two general groups can be recognized. One group comprises those hypotheses, whereby the ball lightnings are afforded an independent existence uninfluenced by external forces; in other words, the ball lightning, as a system in more or less stable equilibrium, is regarded as a source of potential energy[1]). These approaches constitute mere speculations, almost totally lacking any experimental foundation. The second group comprises theories, whereby the energy of the ball lightning is provided by some external source, i.e., the ball lightning is regarded as a system which cannot exist independently but disappears due to the same cause which led to its creation.

The older hypotheses belong, of course, to the first group; here, an uncritical observer is tempted to regard the ball lightning as an independent material body; this view, however, is still encountered in more recent times. Van Mussenbroek[2]), who grouped the ball lightnings and the meteors into one class, namely that of the "météores ignés" — the fireballs — considered the ball lightning to be an accumulation of inflammable substances, which fall under their own weight from the upper strata of the atmosphere, whereby their inner constituents become increasingly hotter until they finally explode. As naïve as this hypothesis dating from the eighteenth century may seem to us, it was nevertheless revived in all its aspects more than a hundred years later by Count Pfeil[3]). He believed that the ball lightnings consisted of a mixture of cosmic dust and snow crystals enveloped by inflammable gases which unite to form balls in strongly electrified clouds and which gradually decrease in size as they descend toward the earth's surface.

153 This approach also forms the basis of the theories of Arago[4]) and Hildebrandsson[5]). Arago also considers ball lightnings to be accumulations of weighable substances consisting of some nitrogen-oxygen compound which is heavily permeated with "lightning matter." Similarly, Hildebrandsson regards the ball lightning as a ball of vapor mixed with oxygen-hydrogen gas or other explosive gases of this type.

According to Moigno[6]) the ball lightning is formed when an ordinary electrical discharge, which initially propagates along a good conductor, is

[1]) Ciel et Terre. 31. 499.
[2]) van Mussenbroek, P. Cours de Physique exp. et math., 3. 405–406. 1769. Leyden.
[3]) Count Lothar Pfeil. Der Ursprung der Meteoriten (The Origin of Meteorites). Gaä 22. 229–231. 424–478. 1886.
[4]) Arago, op. cit. 4, 182.
[5]) Zs. der. österr. Ges. f. Met. 18. 385. 1883.
[6]) Le Cosmos 14. 672–675. 1859.

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suddenly restrained owing to a sharp or ninety-degree bend in the electrical conductor. In Neesen's[1]) view the ball lightning phenomenon involves rapidly flying solid fragments, for example, metal fragments, which are heated to glowing and envelop a strongly heated volume of air.

In other theories the ball lightning is regarded as a turbulent mass. As an example, let us consider the theory developed by V. Carlheim-Gryllenskōld[2]), who proposed that ball lightnings consist of turbulent masses of highly ionized air (tubes tourbillonnaires de révolution) which move under the combined influence of hydrodynamic and electrostatic forces. A modern version of this theory stems from K. Wolf[3]), who regarded the ball lightning as an annular turbulent mass consisting of electrons. This annular turbulent mass emerges at the bottom of the lightning channel; its motion — initially along the direction of the channel — is subsequently determined by the prevailing air currents and orography. Its diameter must be assumed to be larger than meets the eye owing to the scattering of the electrons. (This would clarify the observation that the balls often seem to float at a certain height above the ground.) The air molecules lose electrons due to impact with the excited electrons of the ball and thus emit light which is most intense in the direction of the outgoing electrons; the diffusion of the electrons emanating from the axial tubes gives rise to the pear-shaped and oval form of many ball lightnings or the appendage-like light bundle. The explosion of the balls is caused by the sudden intrusion of the ambient air via a thin portion of the wall, such as can be created when the electrons are torn away by the centrifugal force; the noiseless dissipation of the ball is associated with a gradual intrusion of air into the inner vacuous space.

54 For a while the concept that the ball lightning constituted a body in a spheroidal state was widely accepted. This view was first put forward by Poey[4]), who regarded the ball lightning as a sphere filled with some relatively light gas and surrounded by an extremely fine elastic membrane; the color of the sphere was associated with interference effects occurring upon the reflection of sunlight from the membrane. The basic idea underlying this theory was later revived in a somewhat modified form by E. Alt[5]), who proposed that as a result of the shock created by the electrical discharge individual parts of the electrified clouds are repelled by clouds of like charge and at the same time are attracted to the oppositely charged surface of the earth. Due to the decrease in their volume they acquire a high electric potential, which manifests itself by glowing, and appear in the form of hollow fireballs. Oltramara[6]) also regards the ball lightning as a highly charged portion of a thundercloud which separates itself from the latter, spontaneously assumes a spherical shape and starts to move under the influence of the electric field of the atmosphere.

The theory of de Tessan[7]) can also be included in the first group of theories. Here, the ball lightning is associated with the discharge of a highly

[1]) Neesen, F. Gew. u Blitzableiter. Himmel u. Erde 13, 151. 1900.
[2]) Report on the International Conference of Directors of Meteorological Stations, Innsbruck 1905. K. Zs. Met. u. Geodyn. Annual Supplement 1905, pp. 113—115.
[3]) Prometheus, 26. 229. 1915.
[4]) Comptes Rendus 40. 1183. 1855.
[5]) Met. Zs. 18, 573—576. 1901.
[6]) Comptes Rendus 88, 1319—1321. 1879.
[7]) Comptes Rendus 49, 189. 1859.

charged Leyden jar. The inner "plate" consists of relatively rarefied air having a corresponding conductivity, the outer "plate" is the surrounding humid air, while the insulating layer (instead of the glass) is formed by a dry spherical air layer which is highly compressed owing to the mutual attraction of the charges of opposite sign accumulated on the respective surfaces of the layer. Flammarion[1]) also regards the ball lightning as a type of gaseous Leyden jar. [1])

The theories of the second group have in common that in nearly all cases they are based on laboratory investigations, although in part these theories have only a few of the properties of ball lightning as a starting point. Du Moncel[2]) attempted to produce phenomena similar to ball lightning by connecting the ends of an induction coil to poor electrical conductors. According to his studies, the streak lightnings preceding the ball lightning cause a discontinuity in the conductance of the humid atmosphere, thus producing the ball lightnings. Like the results of the above test, those obtained by v. Urbanitzsky[3]) and Leduc[4]) are superficial. M. Otto[5]) regards the ball lightning as a dreadful endothermic compound of unknown molecular composition, which from the physical standpoint is the same as melinite from the chemical standpoint, and needs only to be released, possibly by mere contact, in order to cause a discharge equal to that of a powerful lightning. To simulate the ball lightning experimentally, he set up two metal platelets 30 mm apart and charged them to a potential of about 30,000 volts. At a certain threshold voltage a fireball was generated which moved to and fro between the two plates with a peculiar hissing noise. The result of this experiment, however, somewhat strangely contradicts the hypothesis of the enormous quantities of stored energy in the ball lightning. [2]) [3])[4])[5])

Starting from the viewpoint that the quantities of charge occurring in static electricity are much too small to cause phenomena comparable to ball lightning, G. Planté[6]) carried out experiments with high-intensity currents, but at the same time at a high voltage, with the aid of a storage battery consisting of 2,000 cells, whose terminals were connected to two wads of paper moistened with water which he took to represent the plates of a capacitor. In this way a small fireball was formed which moved back and forth between the two plates. On the basis of the above experiment Planté reached the following conclusion[7]): ball lightnings represent a slow and partial discharge of the electricity of the thunderclouds which takes place when this electricity has accumulated in extremely large quantities and the cloud proper or the heavily charged humid air column, which, as it were, forms an electrode, almost completely reaches the earth's surface or is separated from it by only a thin insulating air layer. [6]) [7])

However, the correlation between his experimental results and ball lightning involves a number of difficulties, for example, the assumption of a humid air column which is to serve as an electrode. Further, it is hard

[1]) Op. cit.. p. 124.
[2]) Sauter, op. cit., p.4.
[3]) v. Urbanitzky. Die Elektrizität des Himmels und der Erde 78. Vienna—Berlin. 1888.
[4]) Comptes Rendus 129, 27—38. 1899.
[5]) La Nature 29, 562. 2nd Sem. 1901.
[6]) Planté, G. Les phénomènes électriques de l'atmosphère.
[7]) La lumière électrique 286, 1884; Sauter, op. cit., 15.

156 to imagine why such a discharge of large quantities of high-voltage electricity should actually proceed in the form of a ball consisting of glowing, rarefied air mixed with the dissociation products of water vapor and the vapor of the electrode material. Here, as in the theories of the first group, we again encounter the ponderable mass; similarly, one of Planté's many followers — v. Lepel[1]) — generated luminous balls from very fine water droplets or dust particles which displayed a high mobility.

A large number of more sophisticated experiments are based on Planté's studies. In particular, it was Hesehus[2]), who, in collaboration with Georgiewsky, repeated and extended Planté's experiment with the aid of more highly perfected apparatus. They connected a copper plate mounted horizontally 2—4 cm above a water surface and the water surface, respectively, to the terminals of a 10,000-volt a.c. transformer. As a result a bundle of rays emanated from a certain point on the copper plate and was surrounded by a luminous envelope at times conical, oval, or spherical in shape; its color varied between reddish-yellow and bluish-white, depending on the voltage. The flames thus obtained, which were accompanied by a hissing noise, displayed a high mobility, in part faded out but also united again. When they were covered by a container, the vapors of nitrous acid accumulated under the latter. Hesehus then deduced that in ball lightnings the combustion of nitrogen takes place. However, this does not constitute an actual clarification of the ball lightning phenomenon.

Thornton[3]) regards ozone and partially dissociated oxygen as the essential constituents of the ball lightning; this, in his opinion, is borne out by the weight of the ball and its color, which, according to him, is predominantly blue. He ascribes, on the one hand, a certain negative charge to the ball lightning and, on the other, a high energy which is liberated when ozone converts to oxygen. In his view ozone is generated when at the extremity of a negatively charged cloud, from which a lightning has just emanated, the potential is sufficiently high, without causing a new discharge, so that an extensive ionization is effected resulting in the generation of ozone. As soon as this gas reaches a certain volume, the ball develops, is ejected from the
157 cloud and comes down to earth in the form of ball lightning. Since ozone is a highly endothermic compound, it contains a large store of internal energy, which is liberated upon the conversion of ozone to oxygen, causing the explosion of the ball with its consequences.

According to Galli[4]), the ball lightning cannot, at least during the first phase of its development, be electrical in nature, since the balls can roll about the ground for relatively long periods and do not ignite inflammable substances. He explains the behavior of ball lightning as follows. Inside the ball, which could contain secondary variable elements, such as is borne out by the difference in color and odor, there proceeds a gradual increase in the latent energy, whereby the different effects correspond to the respective phases of the energy conversion process. He could not, however, establish the source and nature of this latent energy; nevertheless, he presumably had in mind something similar to the energy created during the decay of radium,

[1]) Met. Zeitschr. 7, 297—301. 1890.
[2]) Phys. Zeitschr. 2, 578—580. 1901.
[3]) Le Cosmos 18, 142. 1913. 1st Sem.
[4]) Mem. della Pontif. Accad. Rom. dei Nuovi Lincei 32, 315. 1911.

when he spoke of "modern research on the structure and transmutation of matter," which would render such a hypothesis trustworthy.

Walter[1]), in turn, again regards the ball lightning as a water bubble formed by water vapors or spraying water which becomes electrified owing to the fact that a large portion of the charge induced by the thundercloud flows toward the extremely highly charged surface of the earth. Thus, the water bubble experiences a repulsion and, consequently, floats in the air like a soap bubble. According to Walter the disintegration of the bubble occurs either as a result of a partial vaporization of the water on the wall of the bubble, or as a consequence of a nearby lightning streak which temporarily neutralizes the surface of the earth at the point in question, whereby the bubble is attracted by the earth and discharges upon contact. On the basis of experiments with electrically charged soap bubbles, which moved rapidly toward oppositely charged metal disks, where they burst with a crackling noise, Walter considers his theory as valid, even though no luminous effects were observed.

At this stage it is impossible to discuss thoroughly all the above-outlined theories of the development of ball lightning. Some of these theories, namely those which are merely speculative, already seem inherently improbable; in other cases, where the theory is developed on the basis of experimental observations, the similarity between the actual ball lightning and the simulated one is limited to only certain superficial properties (color, shape,
158 hissing, etc.). On the other hand, Töpler's[2]) theory, which is based on systematic studies of the various forms of discharges occurring in the open air (i.e., under normal conditions of temperature and pressure), is fairly commensurable with our empirical knowledge of the ball lightning phenomenon. According to Töpler the process of ball lightning discharge should be imagined somewhat as follows: the discharge is initiated by a streak lightning — the initial lightning — in which those quantities of electricity are equalized which can flow into the latter in the shortest period of time. This initial lightning discharge creates a discharge channel, in which under specific conditions a spherically shaped luminous mass can develop owing to the afterflow of electricity. The final phase of the ball lightning occurs either as a result of its noiseless disappearance, when the flow of electricity in the discharge channel ceases, or if the channel once again serves as a discharge path for an ordinary lightning.

Apart from the discontinuous discharge (spark discharge), Töpler studied very thoroughly the near-continuous discharge, which occurs when almost steady-state conditions prevail in the gap between two electrodes, and their different forms (dark discharge, glow discharge, brush discharge, brush arc, flame arc) and interrelationships.

As a source of electricity he used a 60-plate Töpler induction machine, whose current can be assumed constant when large liquid resistors are inserted[3]). All positive and negative discharge forms were maintained as pure as possible, when the electrodes — a large plate and a small sphere — were set up one opposite the other. The experiments, whereby part of the discharge in the gap was suppressed as much as possible, pointed to a dependence of the discharge process on the average current intensity and

[1]) Met. Zeitschr. 26. 217—219. 1909, and Handwerk-Buch der Naturwissenschaften (Handbook of the Natural Sciences).
[2]) Annalen der Physik IV, 2. 560—635. 1900.
[3]) Isis p. 4. 1898.

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the gap width. When the capacitance of the electrodes was vanishingly small, only near-continuous discharges occurred; the transition from one discharge form to another proceeded without interruption, i.e., for a gap width of 2—10 cm the discharge gradually passed with increasing current intensity through all the stages: dark discharge, glow discharge, brush discharge, brush arc, flame arc. Each of the near-continuous discharge types is associated with a specific gap width — current intensity range, within which only the relevant discharge form can exist. However, when the electrode capacitance on both sides of the gap was small, but not vanishingly small, the gradual transition of the individual discharge forms turned into a discontinuous succession of discharges, such as hissing streamers,
159 intermittent brush discharges and, primarily, the actual spark discharge[1]).

Töpler's brush arc is a zonal discharge and possesses all the characteristics of the formation of zones in rarefied gases; thus it does not differ noticeably from the anodal light of Geissler tubes. Both the positive and the negative discharge can assume the form of a brush arc; however, it develops most fully in the negative discharge. In the free air the spherical portion of the zones is always directed toward the cathode, while the tapered portion always toward the anode. The zones are equidistant, provided the width of the discharge channel remains the same, i.e., the current density remains constant. The luminous portions of the overall discharge process — continuous sparks — possess a significantly higher temperature than the dark intermediate spaces. This temperature is so high that it causes, for example, sealing wax to melt and burn like a candle[2]). The color alternates between violet-pink at low discharge intensities and yellowish-pink at higher intensities. A widening of the gap width results in an increase in the number of zones. With increasing current intensity the distance between the individual zones becomes narrower and, if the gap width remains constant, new zones are formed in addition to those already present. The zonal discharge proceeds as follows[3]): first hissing, unsteady streamers shooting back and forth develop at the cathode; then, suddenly, the negative, rather stationary brush discharge occurs at the points in question; this discharge then develops into a pink light point, which shoots across without exhibiting any zonal character. Finally, it spans the entire gap in the form of initial sparks, whereupon the actual overall zonal discharge forms, which can last for several minutes. The zones in general migrate, i.e., are seemingly repelled by the cathode, whereby the migration speed depends on the resistance.

Töpler deduced that each lightning constitutes a retarded discharge of the type which occurs when the charge between a good electrical conductor — the earth — and a poor conductor — the cloud — is equalized. According to Töpler the form of the discharge depends only on the speed at which the charge is liberated in the two source regions and can form an afterflow.

In accordance with studies, in particular those of Walter[4]), carried out on the basis of photographs of lightning with a moving camera, the main discharge
160 is preceded by an appreciable number of preliminary discharges, i.e., it consists of a series of intermittent discharges following one another in rapid succession which continually progress from both sides, whereby extensive

[1]) Ann. Phys. IV, 7, 477. 1902.
[2]) Isis, p. 7. 1898.
[3]) Ann. Phys. u. Chem. 63. 116. 1897.
[4]) Ann. Phys. IV, 10, 393—407. 1903.

branches form at the positive pole. Each preliminary discharge renders an air channel conductive due to ion impact until the main discharge, which proceeds along the dominant branch, jumps solely across the remaining part of the gap width. It is significant that each partial discharge progresses exactly along the initially formed channel. These individual discharges, of course, follow one another in general so rapidly that they can be detected only on a photographic plate. However, cases are also known in which an image, such as that obtained by means of a moving camera, was seen with the naked eye; this is associated with the so-called ribbon lightning. In such cases various main discharges are involved and the images are created one beside the other, since the lightning path is shifted due to wind effects. The time interval between such multiple lightning discharges can even reach several seconds, so that between the individual discharges relatively long periods of darkness can occur.

However, it is also possible that the subsequent flow of charge in the discharge channel does not proceed by repeated jolts but rather in a more or less continuous fashion. The after-discharge can hereby take on the most diverse forms. Frequently it merely consists of an almost uniform flow of charge, which can be manifested by a faint glowing of the discharge channel. This phenomenon is in general also of very short duration and, consequently, only detectable by photographic methods. Occasionally, afterglows lasting 1—2 seconds have been observed with the naked eye, whereby the path of the lightning glowed like the filament of an incandescent lamp when the current is switched off[1]). In the case of intense lightnings such an afterflow of charge seems to occur as a rule[2]).

Thus, in accordance with Töpler's assumption, it now seems that when the afterflow of charge proceeds uniformly, the lightning no longer manifests itself as a glowing filament, but instead as a series of luminous regions along the discharge path in the form of a beaded lightning or ball lightning. The creation of only one single luminous mass requires, in Töpler's view, that the flow of charge in the discharge channel between cloud and earth proceeds in a prolonged and nearly continuous fashion; this would then constitute the phenomenon of ball lightning.

In assessing Töpler's theory it should be mentioned at the outset that his studies are, on the whole, based purely on experiment and that a basic guiding principle, such as can be found in the works of J. J. Thomson and J. Stark on luminous phenomena in rarefied gases, is lacking. Consequently, Töpler is in no position to specify why an intense luminous phenomenon should occur at some particular point or several points of the lightning path. He merely states that it should be assumed that the luminous mass at the same time represents a somewhat constricted portion of the discharge channel and that it is possible that the potential gradient at certain points of the discharge channel attains for some reason extremely high values; then, at a sufficiently high current density the air would start to glow at these points. However, according to the more recent measurements of Holm[3]), the potential gradient in the positive zonal column in rarefied spaces fluctuates in accordance with the brightness of the individual zones. Since Töpler believed that the zonal discharge in the free air is formed by the same laws as in a rarefied gas, then a change in the potential

[1]) Met. Ztschr. 10, 73. 1893.
[2]) Amer. Jour. of Science 5. March 1873.
[3]) Phys. Zs. 9, 558. 1908.

gradient could probably have been the cause for such a zonal distribution of the light glow.

Assuming that it is possible that the ball lightning can develop in the above-described fashion, then it should be further investigated whether and to what extent the ball lightning properties deduced in the previous chapters are commensurable with the requirements and conclusions of this hypothesis.

The first condition for the creation of a ball lightning must be the existence of an initial lightning. This prerequisite seems in general to be satisfied on the basis of the above deliberations on the development of ball lightning. Also the data on the time interval between the initial lightning and the ball lightning, and the site of the appearance of the fireball relative to to the lightning are in good agreement with this theory. Those isolated cases in which the ball lightning was not preceded by any visible electric discharge (181), can be made compatible with Töpler's theory insofar as it can be assumed that such an ionized path can by way of exception also be produced by a nonluminous discharge, i. e., that the lightning is initially invisible and that luminous effects appear only after some time when the current intensity and potential are adequate. Likewise, instead of an initial lightning a brush discharge in the form of St. Elmo's fire could effect ionization (this is probably the case in 59).

However, the dimensions of the ball lightnings must also be compatible with the width of the discharge channel. The data on the diameter of the lightning ball fluctuate between several millimeters and several meters. Nevertheless, the most frequently occurring size was about 10—20 cm, which mainly applies to lightning balls observed near the earth's surface; however, ball lightnings with a diameter of 10 and 50 cm also occurred fairly frequently. The data on the width of the lightning, i. e., of the discharge channel, also differ widely.[1]) The maximum value for a streak lightning is 40—50 cm; however, the actual "core" of the discharge channel is probably only a few centimeters thick; this is borne out by the diameter of flash tubes and the observation that in the lightning traces on basalt the N- and S-magnetization maxima are separated by a distance of only 2—3 cm, and, further, that even powerful lightnings passing through glass windows leave behind holes a few centimeters or even only millimeters in diameter. Nevertheless, despite the wide fluctuation in the data these small dimensions are not compatible with the diameter of most lightning balls. In 199 it is even explicitly reported that the diameter of the luminous balls repeatedly seen after power lightning discharges was about three times the width of the lightning. Here, we encounter a certain inconsistency which requires clarification. Otherwise, we would have to assume that the lightning ionizes not only the actual discharge channel but also the surrounding air column, so that in reality the ionization channel would be much wider than the lightning channel proper. 1)

The splitting of lightning balls which proceeds with a decrease in volume can be explained as follows: the lightning channel forms a system of branches at a point in the vicinity of the lightning ball. Vice versa, in the same way several small balls can unite to form one large ball.

According to Töpler's theory of the formation of luminous zones the shape of lightning balls cannot be perfectly spherical. However, if we

[1]) Töpler, M. Gewitter und Blitze (Thunderstorms and Lightnings), p. 17, Elektrot. Ver. Dresden. 1917.

consider the data in their literal sense, we find a contradiction, since the overwhelming majority of reports speak of the phenomenon as being ball-shaped. However, it was already pointed out that the shape can be designated as spherical only in the first approximation. In addition, if we allow for the fact that also deviating shapes, such as oval and pear-shaped forms and protuberances of the ball have been confirmed, this difficulty seems mitigated, especially since the longitudinal axis of these forms is vertical (only in 196 horizontal), i.e., presumably directed along the discharge channel. Also in those cases where the main glowing mass of the luminous phenomenon possesses an appendage which renders it similar to a bomb with a fuse or a candle light, the point is directed either upward or downward, i.e., probably toward a cloud or earth electrode. Since in positive as well as negative brush areas the points of the Töpler luminous masses are always directed toward the anode, while the wide portions always face the cathode, an analogy can be clearly recognized.

Thus, the occasional observation of a long, extended form of ball lightning would represent a transition to a light development along the entire discharge path (a firestream, as Töpler put it). When Töpler suggests that such a faint glowing, possibly differently colored light column, which is described in a few cases, and which merely constitutes a type of envelope surrounding the actual "core," occurs as a rule, then this is borne out by the fact that the contour of the ball lightning is more often blurred than sharply defined; however, the existence of this column still cannot be considered as confirmed. Changes in form can be compared with the fact that in Geissler tubes the luminous zones also have unstable contours.

The different coloration of the lightning balls could be associated with differences in current intensity. The Töpler luminous masses are bluish at low current intensity, and pass through dark or crimson red, brick-red, yellow-red, and finally whitish as this intensity increases. This color sequence, however, cannot be recognized in the case of ball lightnings. Nothing can be said about the generally high light intensity of the lightning balls in comparison to the brightness of the brush arc, since Topler gave no data on the light intensity of the latter.

The duration of the ball lightning seems to constitute an even more difficult problem. The time specified most frequently in the reports is 3—5 sec. This could be readily correlated with Töpler's theory, since lightning channels lasting for several seconds have been established and since such a duration also seems feasible. However, there also exist reliable, though very few observations, which indicate a disproportionately longer duration, for example, 181, where the total duration of the phenomenon was approximately 2 min, i.e., of a totally different order of magnitude. It nevertheless seems improbable that the discharge channel would persist for such a long time. Thus, in such cases we must assume that enormous quantities of charge capable of maintaining such a long period of ionization have accumulated in the clouds. Further, the air currents must be uniform and weak since otherwise the discharge channel would be rapidly ruptured and an afterflow of charge would become impossible.[1]) Report 199 is an example of a relatively long persistence of

[1]) Schmauss, A. Met. Zs. 35. 184. 1918.

the channel; here, several streak lightnings, a beaded lightning and two ball lightnings proceeded along the same path.

The clarification of the ball lightning phenomenon is rendered even more difficult owing to its kinematic properties. The problem which first arises is that concerning the force which imparts motion to the ball lightning. Changes in the potential gradient are certainly not the sole cause, since the motion can abruptly change. On the other hand, the horizontal motion of ball lightnings can be attributed to a shift in the discharge channel due to wind; vertical movements in the discharge channel must be associated with changes in the current density or explained in analogy to migration of luminous masses which also occur in a brush arc at constant current intensity. The subsequent ascent of many ball lightnings, without first having reached the ground, could then, according to the above assumption, be explained as follows: while the earth represented the cathode, the current intensity in the discharge channel initially increased but then decreased again.

That in most cases the motion of the ball lightning proceeds in the discharge channel is very clearly illustrated in 199, where the balls followed exactly the path of the preceding lightning discharge. This is borne out by the fact that chimneys and flues often serve as a path for ball lightnings, since owing to the conductivity of the flue gases the lightning channel presumably often passes through chimneys or even terminates in them, and by the fact that lightning balls were frequently observed on projecting objects, such as lightning rods, church steeples, and tree tops, where the path of the lightning presumably ended.

The property of ball lightnings to evade people and buildings, on the one hand, or to suddenly jump toward them, on the other, was compared by Töpler to the following phenomenon observed in a brush arc: the presence of an electrically charged metal wire caused a deflection in the discharge path of the brush arc, while a disturbance in the current flow led to a sudden transition of the starting point of the brush arc to the end of the conducting wire. Thus[1]), when a wire was placed near the brush arc emanating from the cathode, the arc was deflected and displayed a bend around the conductor, i.e., the flow of electricity proceeded through the once developed, though longer, discharge channel, since owing to the lower potential gradient along this channel the potential difference is smaller along this path than that which would be required for the development of a new, if even shorter, channel. When the flow of electricity had developed, the arc suddenly jumped over to the end of the wire.

The brush arc also offers an analogy for the intrusion of the ball lightning into closed spaces. When Töpler placed an electrode d between and somewhat closer to the lower of two horizontal slate slabs w and b, between which a brush arc had developed, and blew the brush arc against this intermediate electrode, the arc partly bent around the latter, but also partly flashed over to this electrode. In the latter case it split into two brush arcs, which were fairly independent of one another, so that each could carry out its own motions. Even when one of the arcs (that between d and w) ceased, i.e., was by chance blown out, the lower arc persisted, provided a sufficient quantity of electricity was transferred by glow or brush discharge to the space between d and w. Now, if w represents the cloud, b the ground, and d the roof of a house, then the analogy is given. Once the lightning has intruded into the house, this process can repeat

[1]) Ann. Phys. V, 2, 594, 1900.

itself, since now smaller metal objects, stovepipes, railings, doorlocks are either bypassed or form new intermediate electrodes. In the latter case a sudden shift in the luminous mass toward the intermediate electrode could occur, whereby, as has occasionally been observed for ball lightnings, the luminous mass jumps over to the metal.

If we neglect the possibility of a severe constriction of the balls and assume only that they carry a considerable charge, then, independently of Töpler's theory, the penetration of lightning balls through metals, their passage through cracks, keyholes, etc., can be explained by assuming that these balls behave in precisely the same manner as a spark discharge between which an intermediate electrode has been inserted. A corresponding phenomenon is also observed in the brush arc: when a luminous mass migrating in the discharge channel strikes an intermediate electrode, it disappears at the point of impact and appears again in the form of a luminous mass on the other side of the conductor.

Although it seems that certain fundamental aspects of the kinematic processes of the lightning ball are clarified by Töpler's studies, it should not be overlooked that there still remains much to be explained. For example, an explanation is still lacking for the ability of lightning balls to move in an upward direction. Further, the slow ascent and descent of the balls, as well as the fact that the speed during ascent is as a rule greater than during descent are not commensurable with Töpler's comparison of the motion of lightning balls with the migration of the luminous mass in the brush arc. Moreover, on the basis of this theory it is hard to explain why the lightning balls plunge from cloud to earth with such great speeds as, for example, described in 199. In discharges in rarefied air at a pressure between 8 and 46 mm Hg Töpler obtained pairs of luminous masses, whereby one mass moved slowly away from the cathode, while the other flew rapidly from the anode toward the cathode. However, at atmospheric pressure the luminous masses remained at rest. Quantitative data on the speed at which the luminous masses shifted are not given in Töpler's studies, so that it remains an open question whether their speed was great enough to account for the high vertical speed in the discharge channel.

Further, there also exists doubt whether the often appreciably long horizontal path of the ball lightning can be correlated with a corresponding discharge channel length. Despite Töpler's observation of the exceptional independence of discharges between the intermediate electrodes (which, of course, in the final analysis presupposes a prolonged, constant replenishment of ions), it seems more feasible in such cases that the fireball should perhaps nevertheless be considered as having — within certain limits — an independent existence after leaving the discharge channel due to some unknown reason which enables it to move onward by virtue of its internal energy.

A point, which is likewise difficult to bring into accord with Töpler's theory, is the frequently observed phenomenon of rolling lightning balls (this would seem to imply some kind of spinning motion) and the possibly interrelated emission of sparks and rays — a phenomenon which is clearly illustrated in the only existing sketch of a ball lightning. These manifestations evidently point to an outward flux of electricity. In this respect the lightning balls are more reminiscent of St. Elmo's fire, which

also produces this peculiar hissing, whistling noise. Neither of these two properties is manifested in brush arcs; the brush discharge process as a rule proceeds noiselessly. Nevertheless, Töpler attempted to explain the development of "flickering flames" on the balls by assuming that in such a case the foot of the discharge channel creeps over sections of the ground with differing conductivities (presupposing a higher conductivity of the cloud), which would account for the rattling or crackling noise. If, on the other hand, the earth's surface constitutes the electrode with the higher conductance, then the foot of the discharge channel shifted by the wind could pass without causing any disturbance or noise from the moist ground onto smaller or larger metal objects, telegraph poles, etc., while the luminous mass could calmly float toward these objects. In 132 the ball lightning jumped from a good conductor — a gas bracket — to a second gas bracket in another room; however, here, mention of a cracking noise was made only in connection with the disappearance of the ball. Similarly, in 187 the ball jumped from one of five chimney tops to another; the crack, however, was first perceived when the ball exploded. On the other hand, in 6 the ball fell through a door onto a staircase with a cracking noise. At any rate, here, as well, there seems to be a certain degree of uncertainty.

Further, the fact that lightning balls frequently seem to move at some distance above the earth's surface, the repeatedly observed phenomenon of balls coming to a standstill, the fact that they are capable of resting on a water surface for a short time without being destroyed, their peculiar behavior toward good electrical conductors with which they occasionally seem to "flirt" (as in 152, where the ball lightning alternately approached and moved away from the telephone cables), all lack a satisfactory explanation or are not clarified at all in Töpler's theory.

However, the way in which many ball lightnings cease to exist can, on the whole, be more readily brought into accord with Töpler's theory. When the ball lightning represents a glowing portion of the discharge path, then its noiseless disappearance can, as has been frequently established, be attributed to a cessation in the afterflow of charge in the discharge channel. This can be due to various factors: either the charge of the cloud does not suffice to effect further maintenance of an ion transport, or the channel is ruptured at one or more points by air currents, thus interrupting the supply of charge, or an ordinary lightning discharge shoots downward in the vicinity which equalizes the charges in the cloud and on the earth's surface. All these cases must result in the cessation of the ball lightning, and, in fact, this process will proceed to completion quite noiselessly or, at the most, will be accompanied by the detonation of a new lightning stroke.

Nevertheless, the discharge channel can just as well serve as a path for a new discharge in the form of a streak lightning. This will take place when a momentarily stronger flow of charge is supplied by more remote cloud portions, or when the discharge channel shifted by the wind enters regions possessing ample quantities of charge which can become equalized in the form of a streak lightning. For such a disruptive discharge to occur it would also suffice if only one end of the lightning channel were shifted toward such a region, i. e., either toward an extensive cloud region with a relatively high mean conductivity or toward a highly conducting object with a high capacity on the earth's surface. Such a final lightning discharge has also been observed in a number of cases, which, nevertheless still

constitute a minority; this, of course, would likewise in general characterize the final phase of the discharge process, and, in fact, with a detonation, which again is not associated with the lightning ball but with the final lightning flash. The existence of a final stroke together with the initial stroke would also — as was already pointed out above — explain the manifold effects, which are usually attributed by the observers to the ball lightning. The final lightning discharge could also clarify why many lightning balls upon their "explosion," which would then be only apparent, emit streak lightnings, part of which possess all the known effects of these discharges; above, this phenomenon served conversely as an indirect proof of the existence of a final stroke. Accordingly, it is quite possible that the discharge channel was branched in the vicinity of the site at which the ball lightning occurred.

On the other hand, the widely alleged explosions of ball lightnings cannot be explained by Töpler's theory.

The mostly minor physical effects, in particular the relative harmlessness of most lightning balls to humans, as was established above, can be attributed to the small inherent charge of the ball lightning. Whereas the well-known method of measuring the intensity of the residual magnetization of iron-bearing rocks yields minimum values of about 6,500—20,000 A for the current intensity of an ordinary lightning,[1]) which for a 2-km long lightning discharge of average intensity corresponds to an energy of $10^{15}-10^{16}$ ergs at a potential of approximately 40,000 kV, Töpler obtained, depending on the method of approximation used, values between 2 and 20 A for the current intensity in ball lightnings, i. e., values which are in good agreement as regards their order of magnitude. Such an estimate is effected most simply by assuming that a ball lightning equalizes the same quantity of charge — about 100 C — which an intense streak lightning discharges in fractions of a second, in about 5 seconds, which would give a current intensity of 20 A. Töpler maintains that even a value of 10 A is too high and believes that luminous masses the size of a child's head are already feasible at a current intensity of 0.001 A. He further regards the potential gradient in the discharge channel as relatively low. Without further verification, Töpler estimated this gradient to be even lower than the potential gradient of 1,700 V/cm observed in brush arcs. Thus, in general, the energy of lightning balls cannot be large, which is in accordance with their established relative innocuousness.

The above deliberations show that Töpler's theory is capable of explaining part of the properties of ball lightnings from a uniform point of view. Its significance is all the greater, since it is based on extensive laboratory investigations, which partly yield good analogies to results obtained by observations. Nevertheless, as was pointed out before, it still does not provide an answer to many other problems. The most important shortcoming of the theory seems to lie in the fact that it postulates the development of only one luminous mass in the discharge channel, while the brush arc, which is a zonal discharge, consists of a whole series of luminous regions along the discharge path; furthermore, Töpler's theory provides no satisfactory explanation why the ball lightning develops only at certain points along the discharge path.

Consequently, Töpler's theory has not yet solved the mystery of the ball lightning; however, it could perhaps form the basis for rendering a solution

[1]) Töpler, M. Gewitter und Blitze (Thunderstorms and Lightnings), p. 12.

to this problem possible. It would be very helpful if it were possible to obtain the spectrum of the ball lightning, especially for the elucidation of the problem whether ozone or nitrogen oxides comprise constituents of the ball lightning (these compounds seem to be implied by the red color of most lightning balls). However, owing to the rarity of the phenomenon only exceptionally favorable circumstances would render this possible (so far there exists no photograph of a ball lightning).

The direction in which further studies should be made is demonstrated by the photographs appearing at the beginning of this book, which were kindly passed on to the author by Professor Nippolt. The original photographs were taken by a Norwegian engineer, A. Nielsen. At first sight these photographs give the impression of phenomena corresponding in size and appearance to the above-described forms of ball lightning. The upper photograph depicts a large luminous air mass, from the bottom of which a luminous ball is separating itself. This ball rose, as is borne out by the lower photograph, into the air, leaving behind the residual diffusely luminous air on the right. In the second photograph the ball seems to be darker at the center than at the periphery, which perhaps may be explained by assuming a luminous hollow sphere. This ball-lightninglike phenomenon appeared during a trial test on a 12,000-V, 10-MW generator. A liquid resistance was connected in parallel to a short-circuiting device and the generator, after being charged, was shorted at maximum voltage via the short-circuiting device. As a result ball-lightninglike luminous phenomena appeared at the shorting point.

Unfortunately, despite repeated inquiries by letter, no further information could be acquired from Nielsen on the test arrangement and the devices employed. Owing to the large size of the machines in question a repetition of his test could not be implemented. Further, due to the prevailing economic conditions no large firm or electric-power plant could be put at our disposal.

Such phenomena, however, should certainly be known in power engineering. Here, we are dealing with electric arcs, which owing to their high temperature cause an air flow which can become so strong that the flame is actually torn loose and remains visible for a short time.

Nielsen made the following additional observations. In one case an intensely luminous ball was seen as it shot out of the high-tension cables (120 kV, 22.4 MW). The ball had a diameter of about 50 mm and was blown a distance of about 50 m by the wind, after which it split into several smaller balls. The phenomenon was the direct cause of a short at the other end of the cable, about 7 km away from the point where the ball appeared. The second case occurred when 22.8-MW generators in a power station were shorted. One generator partly burnt out, but, since it was completely enclosed, no fire phenomenon was observed in the station; however, two small luminous balls were ejected via the ventilation openings of another generator connected in parallel to the first one. The generators were immediately checked and were subjected to a test voltage, but no cracks in the insulation could be found. Consequently, it should probably be assumed that the balls constituted purely electrical phenomena, which propagated even through the heavy insulation of the generators.

Even though a clear picture of the phenomena observed by Nielsen cannot be gained from his brief description, it nevertheless seems possible to obtain photographs of ball-lightning like phenomena with the aid of a short-circuiting device; these, however, will presumably differ significantly from the luminous forms manifested in Töpler's brush arc owing to the widely differing test conditions. In any case, as long as further analysis of the factual evidence is lacking and systematic investigations are not implemented, the dissipation of the ball lightning will remain a problem.